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GEOLOGY OF McKITTRICK OIL FIELD AND VICINITY, KERN COUNTY, CALIFORNIA[1]

J. A. TAFF[2]
San Francisco, California

ABSTRACT

The structure of the oil-producing Pliocene strata of the developed McKittrick field, together with several square miles of related underlying Monterey Miocene shales on its western border, are concealed by an over-riding mass of disorganized Monterey shale from the middle adjacent slopes of the Temblor Range. The interpretation of the structure of the McKittrick field as given by Ralph Arnold and Harry R. Johnson, in *United States Geological Survey Bulletin 406* (1909), is that of thrust faulting with movement of Miocene strata over Pliocene in an easterly direction.

The writer summarizes briefly the geology of the McKittrick area and presents his conception of the structure as here outlined. The formations, in order of age, and their thicknesses are: (1) Basement complex, schist, marble, and granite, (2) lower Miocene, Temblor sand and shale, 1,200+ feet, (3) middle and upper Miocene, Monterey and Santa Margarita organic shale, 5,000–7,000 feet, (4) lower Pliocene, Etchegoin sand and shale, very thin to 1,000+ feet, (5) upper Pliocene, Tulare sand and shale, very thin to 1,000+ feet.

Beginning in the Pleistocene, a very large segment, approximately 1 mile wide and 6 miles long, of the eastern front of the Temblor Range, composed here of a great thickness of crumpled and fractured Monterey (Maricopa) shale, was moved by gravity northeastward and downward, nearly 2,000 feet, for a distance of 2–3 miles over the eroded edges of the upper Miocene and Pliocene strata, and overlapping and capping the lower Pliocene oil-bearing beds which now produce the oil of the McKittrick field. The gravity movements of the Monterey shale down the slopes of the mountains have been progressive and are now going on periodically in the upper part of the broken mass of shale at elevations ranging from 1,500 to 2,000 feet above the McKittrick field

INTRODUCTION

A report on the geology of the region including the McKittrick field, published in 1910,[3] established the classification of the strata

[1] Presented before the Association at the Oklahoma City meeting, March 25, 1932. Manuscript received, May 12, 1932.

[2] Associated Oil Company, 79 New Montgomery Street.

[3] Ralph Arnold and H. R. Johnson, "Preliminary Report on the McKittrick-Sunset Oil Region, Kern and San Luis Obispo Counties, California," *U. S. Geol. Survey Bull. 406* (1910).

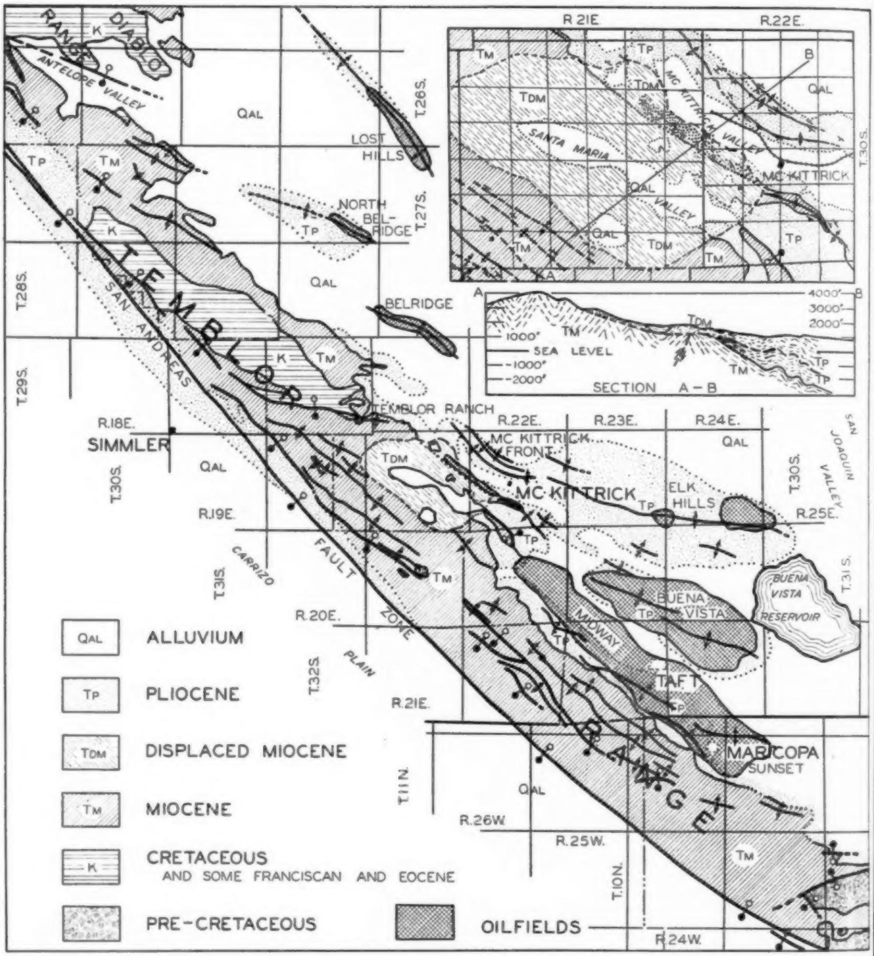

Fig. 1.—Geology of Temblor Range, California, with enlarged map and geologic section of McKittrick district. Average width of township or range, 6 miles. Vertical scale of geologic section in feet.

which has been modified only slightly by later explorations. The general structure of the region was mapped also, but as the peculiar and complicated structure of the McKittrick field, in the opinion of the writer, was not understood, it was not correctly interpreted. A discussion of the phenomena bearing on this structure, and an attempt at its correct interpretation, is the main object of the writer. The general geology and structure of the region is briefly outlined preliminary to the discussion of the structure of the McKittrick field.

LOCATION AND GENERAL RELATIONS

Figure 1 shows in miniature and in condensed form the geology and structure of the Temblor Range and borderlands of the San Joaquin Valley and Carrizo Plains. The McKittrick area is situated in the foothills near the center of the northeast side of the range at the border of the San Joaquin Valley, and an enlargement of it is shown in the northeast corner of the map.

The Temblor Mountain Range, 70 miles long and 12 miles wide, connects with the Diablo Range on the northwest and the San Emigdio Mountains on the southeast. The Lost Hills, a part of the physiographic and structural unit which includes the Kettleman Hills, is an offshoot into the San Joaquin Valley from the Diablo Range, and the North Belridge, Belridge, and McKittrick hills, and the Elk Hills, and the Buena Vista Hills, with their oil fields, are divergent structural offshoots into the west edge of the Great Valley from the Temblor Range. The character of these *échelon* topographic and structural units in which the several oil fields are situated, seems to have developed progressively outward into the valley, from the mountain ranges. The McKittrick and Midway fields are, in general, monoclinal in the border of the Temblor Range and in line with the general trend of the mountain structure.

GENERAL GEOLOGICAL RELATIONS

The older metamorphic rocks, generally designated "Basement complex," are of two classes in the Temblor Range. One is the Franciscan, metamorphic sedimentary rocks, with a series of intrusive basic volcanic rocks generally metamorphosed to serpentine. This complex occurs beneath the Cretaceous and Tertiary sedimentary rocks in the northern half of the range. The second class of the Basement complex underlies the southern half of the Temblor Range, is composed of granitic rocks with schists and crystalline limestone in-

clusions, and, where exposed in the crest, the Tertiary strata lie directly on it. This granitic mass seems to be the northwesterly extension of the granitic magma making the cores of the Tehachapi and the San Emigdio mountains, probably parts of one great batholith, including that of the Sierra Nevada Mountains. The line of separation between the two basement masses transects the Temblor Range at a sharp angle bearing southeasterly toward the McKittrick area; thus it is probable that both Cretaceous and Eocene strata may underlie the McKittrick field.

The succession of sedimentary formations in the Temblor Range and in the vicinity of the McKittrick field, is listed as follows:

	Feet
Pleistocene and recent lacustrine and alluvial deposits	0–1,000±
Pliocene and early Pleistocene, Tulare, fresh-water gravel, sand, and clay	3,000±
Pliocene, Etchegoin, marine, gravel, sand, and clay	0–4,000±
Miocene, Santa Margarita, marine, conglomerate, sand, and diatomite	2,000±
Miocene, Monterey, marine, diatomite with local limestone and sand strata	5,000±
Miocene, Temblor, sand and foraminiferal shales	1,200–3,000+
Eocene, Tejon and Kreyenhagen sandstone and foraminiferal shales	0–3,000+
Cretaceous, Knoxville shales and Chico sandstone	0–9,000

SEDIMENTATION

Cretaceous and Eocene.—As already stated, Cretaceous and Eocene sedimentary rocks overlie the metamorphic series in the north half of the Temblor Range. The Knoxville and Chico formations of the Cretaceous in the south end of the Diablo Range which joins the Temblor Range on the north, have a total thickness of approximately 5,000 feet and 4,000 feet, respectively, of dark shales and drab sandstone. Both here, and in the north half of the Temblor Range, folding, faulting, and erosion occurred between the Cretaceous and Eocene periods of deposition. Then 3,000 feet or more of Tejon sandstone and shales were deposited unconformably upon the Cretaceous. Both the Cretaceous and Eocene formations decrease in thickness south-

ward in the Temblor Range, and pass diagonally from it beneath the Miocene strata trending southeasterly toward the McKittrick area and beneath the San Joaquin Valley.

Miocene Temblor formation.—Marine sedimentation began in the area now occupied by the Temblor Range adjacent to the McKittrick field near the close of lower Miocene time. Conglomerate, sand, and foraminiferal shales in alternate series accumulated to depths of 1,200 feet in the northern part, to 3,000 feet or more in the southern part of the range, making the Temblor formation.

Miocene Monterey (Maricopa) shale.—Sedimentation continued without interruption through middle Miocene until 4,000 or 5,000 feet of Monterey (Maricopa) organic shales had accumulated. The first few hundred feet of the formation consists of brown foraminiferal shales and some bentonitic clays. Following these basal shale deposits conformably, there is a uniformly variable formation of thinly stratified and laminated siliceous diatomaceous shales, with a few thin bands of limestone and calcareous concretions. At a stage nearly 1,000 feet below the top of the Monterey, there was an emergence of land near the southern end of the range, causing interruption in the deposition of diatomite in the region south of McKittrick. In this area, light colored granitic or arkosic sands were deposited alternately with diatomaceous shales. The sand strata range from thin partings to 100 feet in thickness, and include solidified sand and shale boulders. Farther north, the diatomitic shales were deposited uninterruptedly. This upper member of the Monterey series aggregates approximately 1,000 feet in thickness.

Miocene Santa Margarita.—At the close of the Monterey deposition, there was further elevation of the land, with the exposure and erosion of the recently deposited Monterey in the southern part of the range, thence eastward through the San Emigdio mountain area at the south end of the Great Valley. The beginning of this interrupted sedimentation inaugurated the Santa Margarita deposition in upper Miocene time. At this stage, there were deposited, in the region of the Temblor Range south of McKittrick, and in the San Emigdio area adjoining on the southeast, extensive accumulations of arkosic sands with granite boulders unconformably upon the Monterey shales. Deposition of diatomite was resumed over the boulder-bearing sands and conglomerate south of McKittrick. North of McKittrick, Santa Margarita diatomite was deposited uninterruptedly upon the Monterey organic shale and in apparent conformity therewith. The total

accumulation here of the Miocene organic shale is in excess of 7,000 feet. Approximately the upper 2,000 feet is Santa Margarita.

At, or near, the close of the Miocene diatomite deposition, the area of the Temblor Range emerged with upwarping and faulting of the Miocene strata along the axial part. The sea withdrew westward and into an arm or embayment of the San Joaquin Valley.

Pliocene Etchegoin formation.—Near the beginning of Pliocene time, submergence of the Temblor Range area was again resumed. Pliocene conglomerates, sands, and clays in variable succession accumulated, and successively higher strata overlapped westward upon the eroded edges of the Miocene diatomaceous shales. Submergence and deposition continued at an even pace until a series of several thousand feet of marine sand and clay of the Etchegoin formation had accumulated in the valley, and, to a progressively less thickness, on the lower flanks of the Temblor uplift. Deep wells in the Buena Vista and Elk Hills areas and in the McKittrick Front revealed fine sediments in the lower Pliocene in apparent conformity with the Miocene shales.

Near the middle of the Pliocene, the rise of the Coast Ranges cut off the Great Valley embayment from the Pacific and soon brought to a close the deposition of marine Pliocene in this valley, and ended the Etchegoin formation.

Pliocene and Pleistocene Tulare (Paso Robles) formation.—In the progress of the continued rise of the inland sea, then occupying the Great Valley, the waters changed from saline to fresh and the fresh-water sedimentation continued uninterruptedly in the valley while successively later strata overlapped westward upon the bevelled edges of the marine Pliocene and Miocene formations. Deposits of gravel, sand, and clay with local calcareous strata continued in alternating series until an undetermined stage in Pleistocene time and the completion of the Tulare lacustrine formation. At a stage following the Tulare deposition in the Pleistocene, the inland fresh-water sea of the Great Valley was drained due to the cutting-through of the Coast Range barrier by Sacramento River at the Carquinez Strait. The total thickness of the Tulare sedimentation is not determinable on account of subsequent deposition of local lacustrine, fluviatile, and subaerial deposits from the Sierra Nevada and Coast Ranges which have continued throughout the San Joaquin to the present. The Tulare formation, revealed in deep wells in the Kettleman Hills and Elk Hills uplifts at the border of the valley, is in excess of 3,000 feet, and is in ap-

parent conformity with the Etchegoin. Toward the Temblor Range, however, there is progressive thinning and unconformable overlap of the Tulare upon the bevelled ridges of the Etchegoin, and in places continued upon eroded Santa Margarita and Monterey organic shales.

STRUCTURE

Preliminary to the discussion of the structure of the McKittrick field, the general structural features of the Temblor Range are here pointed out. The folding and shearing of the Miocene strata of the Temblor Range antedated, and doubtless were the contributing causes of, the McKittrick field structure.

GENERAL STRUCTURAL FEATURES

Figure 1 indicates the main anticlinal axes and associated fault traces and the Great San Andreas fault rift which lies just west of, and parallel with, the axis of the range.

As pointed out in the discussion of sedimentation, the first indication of disturbance of the sedimentary rocks in the vicinity of McKittrick was near the end of organic shale deposition in middle Miocene time when there was considerable elevation of the granitic Basement complex in or near the south end of the Temblor Range and at the same time, probably, there were movements in the San Andreas rift. At the close of the Miocene there was regional emergence of land extending through the area of the Temblor Range and for some distance into the western border, at least, of the San Joaquin Valley. Faulting and folding in the range in late Miocene and early Pliocene was restricted mainly to the central part of the range. Following a somewhat general subsidence of the area with advance of the sea toward the center of the range during lower Pliocene, there was revived structural activity with uplifting of the Coast Ranges near middle Pliocene when the Pacific Ocean was excluded from the Great Valley. Doubtless, movements in the San Andreas rift, with faulting and folding of the Miocene strata in the axial part of the range, were in progress. Following the close of the Tulare (Paso Robles) deposition in the Pleistocene, all of the principal "structures" of the Temblor Range were activated, and those in the border of the San Joaquin Valley were inaugurated. Folding and faulting continued and are doubtless still in progress.

The closely compressed and intricate folds and faults in the thick but incompetent Miocene strata in the crest of the Temblor Range,

and the tendency of the more open folds in the foothills to overturn westward, suggest an eastward movement or underthrusting of the granitic Basement complex during the development of the Temblor Range.

The McKittrick field has two distinct stages of structural development.

STRUCTURE OF McKITTRICK AREA

The McKittrick field has two distinct stages of structural development.

The first stage was developed in middle or late Pleistocene. At that stage, the "structures" of the Temblor Range were developed essentially as at present and the McKittrick oil pool was in all essential respects like that of the North Midway field. The formations in monoclinal structure at the base of the Temblor Range were exposed and dipped toward the east; Miocene organic shales, the oil-source strata, 4,000–5,000 feet thick, lay at the base, with Etchegoin sand, oil saturated, resting unconformably on them. Tulare sands and shales rested unconformably on the Etchegoin and overlapped on the Monterey shale at the north end of the developed field. The exposed edge of the Etchegoin sands seeped heavy oil and beds of brea had accumulated in that position, as now proved by some wells in the southwest side of the field.

The entire outcrop of the Etchegoin and related formations is at present concealed by an overflow of Miocene as revealed by the development of the McKittrick field extending from Sec. 10, T. 30 S., R. 21 E., to Sec. 20, T. 30 S., R. 22 E., a distance of 4 miles.

The second structural stage of the McKittrick field developed in late Pleistocene or Recent time when segments of the Monterey shale in the northeastern front of the Temblor Range across the central part of T. 30 S., R. 21 E., were broken down and moved in successive stages 2,000–3,000 feet vertically, and a maximum of 2 miles laterally over the exposed edges of the oil-bearing strata of the McKittrick field.

This interpretation of the structure of the McKittrick field, in the opinion of the writer, is adequately supported by (1) the physiographic features of the northeastern slope of the Temblor Range from which the land mass moved, (2) the topographic character of the displaced rock, (3) the character and water content of the basin fill of the Santa Maria Valley formed in the wake of the moved rock masses, (4) the attitude of the disorganized Miocene shale which over-rode, and

now conceals the Pliocene oil-bearing strata of the McKittrick field, and (5) the secondary oil- and water-content of the overburden of shale. These phenomena are considered briefly in conclusion.

The Temblor Range opposite the McKittrick area is 4,000–4,300 feet in elevation, the highest part of the mountains. Its easterly face at this locality extending from the crest down 2,000 feet is the steepest part of the range, is slightly concave or amphitheater-like, and is scored by sharply cut gulches which end at the base of the steep escarpment in a line of active landslides. From this line of broken and sliding ground, downward to the Santa Maria Valley, a distance of 1.5 miles, the grade is gentle over even slopes and low hummocky hills. The surface rock is entirely fragmental Miocene siliceous shale. Excepting in the more hilly section near the south end of this area, the drainage is downward through the detrital rock. Drainage from the gulches descending in the steep escarpment of the mountain, sinks in local basins at the upper edge of the area of the broken strata, the basins having been produced by active caving or sliding at the mouths of the gulches due to excess water. Some of these basins are several acres in extent.

The Santa Maria Valley is an elongate filled basin parallel with the Temblor Mountain front, 6 miles long and 0.5 mile wide, situated near the middle of the McKittrick area. West of it, and up to the base of the escarpment, is the more recent slide- and debris-covered slope just described. On the east is the earlier, thicker, and more extensive area of displaced Miocene which covers the McKittrick oil pool. Its movement eastward from the mountain front gave place for, and caused, the Santa Maria Valley basin. The maximum depth of the Santa Maria basin is nearly 800 feet and it is filled with alternating recent lacustrine yellow clay, sand, and gravel and coarse detrital rock material. It is now being modified and overrun by sheet flood wash from the mountain slope on the west, and is being attacked by erosion in the east side and south end.

Extending from the eastern border of the Santa Maria Valley to the eastern border of the displaced Monterey shale, there is a group of three parallel knobby terrace-like ridges, each having an average width of 0.5 mile, and lying at successively lower levels of 200–400 feet. The topographic features expressed in these wave-like ridges are not influenced in any way by the character of the rocks. All are composed of crumpled and broken Miocene organic shale with a few remnants of small debris-filled basins which have collected between the

ridges. The more recent are in process of accumulation, and some of earlier development show warping or displacement due to the contiguous moved shale masses. The easterly front ridge of disorganized Monterey shale at its north end, in Sec. 2 and 11, T. 30 S., R. 21 E., seems to occupy a valley or depression on the eroded surface of the Pliocene Tulare formation. The crumpled Miocene shale lies on regular easterly dipping Pliocene sand and shale strata and abuts against a ridge of the same Pliocene formation. The partly filled Frazer Valley lies behind, and west of, this front ridge and Frazer Spring issues from its lowest point. This valley is neither structural, nor apparently erosional. The only plausible explanation is that the northern section of this front ridge of displaced Monterey shale has moved eastward, leaving the valley in its wake.

A thorough research of the results of all the drilled wells in the McKittrick field shows that the overplaced and distorted Miocene shale 300–800 feet thick rests on an uneven eroded surface of upper Miocene Monterey shale and Pliocene Etchegoin and Tulare shale and sand strata. The records show that this eroded floor is undulating but has an average gradient gently downward toward the east. The oil-bearing Pliocene strata seem to be somewhat warped and dip eastward 15°–20° in the north and central parts of the field. From the central part of the area, the dip of the Pliocene gradually increases southward to an almost vertical position at the southern end opposite the town of McKittrick. Farther south, it becomes a part of the northeast flank of the southward pitching McKittrick anticline. The records of wells in the east edge of the field, north of the center, show that the eastern edge of the overthrust Miocene shale is overlapped and concealed by the late Pleistocene or Quaternary stratified sedimentary deposits and alluvial wash. This condition is indicated also by the smooth eastward sloping surfaces of the Miocene blending with the flatter surface of the alluvial deposits of the McKittrick Valley. The contact of the Miocene on the Pliocene in the eastern edge of the McKittrick field rises southward from the center, emerging at the surface near the south end. In this southern section of the field, the overthrust Miocene shale forms a rugged eastward facing escarpment composed of tar-saturated, broken, diatomaceous shale, oil seepages, and wasting brea beds.

Additional and conclusive evidence of the gravitational overthrust and superficial nature of the Miocene shale in the McKittrick oil-field area is the extended invasion into it of fresh waters down to

the undisturbed bed rock. With minor exceptions, the entire rainfall on the eastern slopes of the Temblor Range for a length of 7 miles is absorbed into this area of broken and dislodged Miocene shale. The run-off from the upper slopes of the mountain is discharged into and through the upper slide area, completely fills the basin of Santa Maria Valley, and saturates the hills adjacent and east of it to the eastern edge of the oil field. Springs issue from the eastern edge of the first range of hills east of Santa Maria Valley. Wells in the McKittrick field encountered fresh water in the overburden of Miocene shale, which water becomes sulphurous near the base in contact with the oil-bearing Pliocene sands. Wells drilled in the Santa Maria basin filled to a maximum depth of 800 feet; also wells in the first line of hills east of Santa Maria Valley, and in the vicinity of the springs in the east side of these hills, produce an abundance of fresh water for the oil fields and McKittrick town supply. This draft on the ground water, in conjunction with the recent cycle of low precipitation, has lowered the water table in Santa Maria basin and reduced the invasion of fresh top water into the oil measures of the McKittrick field.

CONCLUSION

The uplifting of the Temblor Range and the folding and faulting of 5,000 feet of incompetent organic Miocene shale are the primary causes of the McKittrick structure. Secondarily, it is probable that during late Pleistocene time when the major movements of the shale masses took place, rainfall was much greater than at present. Under these circumstances, when masses of broken porous shale in a steep mountain slope become saturated with water, they move as a fluid mass under the influence of gravity until the gradient becomes gentle. There are many places in the mountain areas of California where thick incompetent folded and sheared shale formations are subject to progressive slide movements of both small and great proportions, following periods of extended rainfall. One such area as great as that at McKittrick involves the Miocene shales in the steep northerly slopes of the San Emigdio Mountains at the south end of the San Joaquin Valley and such slide movements in a considerable part of the area are still in progress.

No evidence of thrust faulting such as to account for the displacement of the Miocene shale which envelops the McKittrick field and contiguous areas of Miocene and Pliocene strata can be found. Faulting of local nature occurs at the southeast end of the area and there are

indications of some shearing in the east limb of the McKittrick anticline opposite McKittrick with fractures almost vertical, whereas in the opposite, northwestern end of the area, no faulting is apparent.

DISCUSSION

D. DALE CONDIT, Santa Monica, California (written discussion received, July, 1932): When Arnold and Johnson investigated the geology of the McKittrick district in 1908, they recognized thrust faulting and were sufficiently courageous to represent in their published description a text figure in support of this idea.[1] They were, however, hesitant about thus committing themselves on their maps, Plates I and II, which show only two small transverse faults both of which they questioned. In 1927, Walter English[2] stated that detailed mapping by him indicates the presence of a low-angle overthrust fault, but that it is complicated by many minor thrusts, and by a series of steep-hade strike faults. The latter, rather than the overthrust, according to him, determine the position and structural relationship of the productive sand bodies, though the overthrust shale does at some places form a roof over the productive sands.

Although these earlier explanations have gained wide acceptance, Mr. Taff now lays them aside in favor of the view that the extensive over-riding shale mass has moved out from the adjacent flank of the Temblor Range as a landslide on a magnificent scale. On his map he refers to this as the "Displaced Miocene" and in his descriptions characterizes it as "disorganized." He reviews several lines of evidence as follows: (1) certain physiographic features on the north slope of Temblor Range whence he believes the landslide material was derived; (2) topographic character of the displaced rock; (3) character and water content of Santa Maria Valley which valley he regards as having formed in the wake of the moved rock masses; (4) attitude of the disorganized Miocene shale which overrode the Pliocene of the McKittrick field; and (5) secondary oil and water content of the overburden of shale.

Presumably, the views of Mr. Taff as to ground-water conditions and other subsurface data within, and adjacent to, the field are to be regarded as authoritative in view of prolonged study of these problems by him and his associates. As regards his other items of evidence, however, one wonders whether he has attempted, systematically, to trace the more pronounced faults within, and adjacent to, the field, some of which are regional in extent, and the ensemble pattern of which strongly supports the idea of dynamic manifestations in the restricted geologic sense, rather than of lines of dislocation in a slide produced merely by gravity. Those who have carried on detailed mapping with the aid of air photographs recognize what appear to be successive lines of faulting rather than the very few known from published data. The measure of their magnitude of displacement need not remain a

[1] "Preliminary Report on the McKittrick-Sunset Oil Region, Kern and San Luis Obispo Counties, California," *U. S. Geol. Survey Bull. 406* (1910), Fig. 2, p. 97.

[2] "Notes on the McKittrick, California, Oil Field," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 11, No. 6 (June, 1927), pp. 617–20.

matter of doubt since we have, as a geolog'cal "measuring stick," the neighboring Chico Martinez Creek exposures oı Miocene shales, 7,200 feet or so in thickness, which have been measured stratigraphically and divided into successive fossil zones by the micropaleontologists. As a further check we have related evidence from certain deep drilling at various points southward from the area.

The picture as to the structure derived through such means, bears out the idea of successive zones or lobes of thrusting which, in cross section, appear as soles of low inclination with upturned fronts. Outcrop sampling at short intervals across some of the larger faults reveals displacements of 2,000 feet or more, stratigraphically, on adjacent sides. An interesting feature as regards large parts of the successive fault blocks is that though the shales commonly show more or less plication and distortion, they are not properly to be considered as disorganized because, in large parts of the interfault areas, the strata lie in orderly sequence with folded structure and local anticlinal features which in some places are traceable for distances of a mile or more. Elsewhere, however, the confusion is commonly intense, particularly in the hills immediately southwest from the central part of the field, Sec. 13 and 14, T. 30 S., R. 21 E., where broad zones of movement have locally destroyed the bedding of the siliceous shales and reduced them to a granular mass. Topographic features here such as arcuate, billowy ridges and depressions bespeak not only the intensity but also the recency of action. In this same vicinity transverse faulting also is recognizable and extends southwestward in discontinuous exposures through Sections 14, 23, and 27 with a probable persistence up the flank of the Temblor Range. Adjacent to it along the base of the range is a prominent manifestation of what I regard as fault topography with fault-line scarps and sag depressions, one of which covers an area of 20 acres or so and is of such magnitude as to be represented on the McKittrick topographic sheet, of 100-foot contour interval. Mr. Taff apparently takes note of this same ground and ascribes the peculiar topography to caving and sliding at the mouths of gulches, due, as he states, to excess water of a time when the rainfall may have been considerably greater than now.

As regards Santa Maria Valley, a long, trough-like basin parallel with the regional topographic trĕnd, and which Mr. Taff conceives of as formed in the wake of the moved rock masses, it is of interest to note that the gravelly fill 800 feet deep in the valley according to him, laps up on the slopes of the ridge on the north with southward dips approximating those of the underlying Miocene shales which compose the ridge. Furthermore, the summit of this ridge shows remnants of transverse northward drainage lines which have become reversed and ponded, presumably through tilting incident to the thrust-fault movement. Thus the southward dipping strata of the north side of Santa Maria Valley lend support to the opinion that this topographic trough is synclinal. If this is true, the evidence should be substantiated by outcrops on the south side. Evidence as to this is obscured by a mantle of recent outwash material which conceals the older gravel deposits as well as the shales. It is significant, however, that structure of anticlinal aspect borders the valley on the south in Sections 18 and 20.

For these reasons, it seems to me that, at the very least, a modification

of Mr. Taff's views is required. If he holds to his landslide idea as explanation of the manifestations in the McKittrick district, he must concede that his "Displaced Miocene" (and Pliocene, Pleistocene et cetera) have subsequently been extensively modified by faulting as a part of regional deformation.

Unfortunately, the limits of this discussion do not permit use of illustrative maps and cross sections such as are necessary for setting forth convincingly the field relationships which I believe to exist. In closing, however, I wish to emphasize that the most conclusive evidence of the important factor of thrust faulting throughout the area is to be seen in a regional mapping of all the foothill part from the Midway oil field northwest to Temblor Range. With the broader relationships thus in view it seems evident that the thrust faulting is not merely a local feature but that it is more or less persistent throughout this entire front.

J. A. TAFF (reply received, August, 1932): Mr. Condit's discussion indicates that he has adopted overthrust faulting which was hypothetically pictured for the structure of the McKittrick field by Arnold and Johnson.

In the beginning of his discussion of the structure Arnold remarks: "The McKittrick field offers the most difficult structural problems of all the California districts so far examined. . . . As it is, many problems remain quite unsolved and many of the conclusions drawn are still open for discussion." The sections (Fig. 1 and Pl. 5) illustrating Arnold's views of the structure, are labelled "ideal" and "hypothetical" sections, respectively. He states that "Monterey and Santa Margarita (?) (Miocene) formations are thrust practically horizontally northeastward for more than a mile at the point of maximum displacement over the McKittrick (Pliocene) beds." He was unable to map the fault traces of this overthrust block assumed to have been moved a mile eastward on a 4-mile front from the Temblor Range.

A fault block of the nature and magnitude indicated thrust northeastward from the Temblor Range should be easily traceable to the core of the Temblor Range, transgressing other longitudinal fault and fold "structures" mapped by Arnold and Johnson. As a fact, such evidence of thrust faulting it not present to the knowledge of the writer, after conducting detailed areal mapping of the entire Temblor region opposite the McKittrick area. To his knowledge also, structural features of more than local nature are easily traced and mapped in the Temblor Range northwest, southwest, and southeast of the McKittrick area here discussed.

The Monterey (Maricopa) shale, a marine laminated, largely diatomaceous sediment, is not known to yield fresh water until broken down and leached of soluble mineral contents by circulating meteoric or impounded surface waters. Such occurrences of fresh water in broken and displaced Miocene shale are common in the McKittrick area and are found in many wells and springs; also at several places in the San Emigdio Mountains and elsewhere under like circumstances. At known fault contacts in the Temblor Range, alkaline and sulphurous waters are found issuing in springs of small volume.

Mr. Condit's picture of his idea "of successive zones or lobes of thrusting which, in cross section, appear as soles of low inclination with upturned fronts," and his statement that "topographic features here such as arcuate, billowy ridges and depressions bespeak not only the intensity but also the

recency of action" described in the fourth paragraph of his discussion, are clear descriptions of gravitationally displaced masses of folded and sheared incompetent shale formation as exhibited in the McKittrick area, in the San Emigdio Mountains south of Wheeler Ridge, and on a smaller scale in the Ventura region and elsewhere in California.

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DARST CREEK OIL FIELD, GUADALUPE COUNTY, TEXAS[1]

H. D. McCALLUM[2]
San Antonio, Texas

ABSTRACT

The Darst Creek oil field, the fourth Edwards limestone field in southwest Texas, was discovered July 18, 1929, in eastern Guadalupe County. It is located along one of a series of *en échelon* faults parallel with, and southeast of, the Balcones fault zone of Texas.

After migrating up-dip from the southeast, the oil in this field was trapped in the upper 50 feet of the porous Edwards limestone, which was faulted in juxtaposition with the impervious beds on the downthrown side of the fault. In addition to wells producing from the Edwards, there are several producing from fault plane cavities, and two supposedly producing from reworked serpentine deposits. The maximum vertical displacement along the fault is calculated on top of the Austin chalk to be approximately 550 feet.

The surface beds in the area are Middle and Upper Indio sandy clays of Eocene-Tertiary age. Aside from fault planes, the structure is evidenced on the surface by steep dips, a decided down-dip swing in the Indio-Carrizo contact, and a repetition of Upper Indio.

The productive area of the field, including the Appling area to the northeast, consists of approximately 1,670 acres. It is 6 miles in length and in places exceeds 4,000 feet in width. Out of the 291 wells drilled in the area, only 19 are dry holes. The total production through December, 1931, was 19,700,340 barrels. The oil has a paraffine base, a deep green color, and a gravity of 36° Bé.

As proration has been in effect since the field was discovered, the development has been very slow. This, however, has proved beneficial by delaying the encroachment of sulphur water, and tending to increase the ultimate recovery of oil.

INTRODUCTION

The Darst Creek field is the result of an accumulation of oil along the southeast or upthrown side of one of a series of *en échelon* faults which parallel the Balcones fault zone of Texas. It is comparable with the other Edwards limestone fields in southwest Texas, namely, Luling, Salt Flat, and Larremore, the latter of minor importance.

The field is in eastern Guadalupe County, 12 miles east of Seguin, and 45 miles northeast of San Antonio. As it lies approximately 23 miles southeast of the Balcones fault zone, it is included within the general region known as the Texas Gulf Coastal Plain. The topogra-

[1] Read before the Association at the San Antonio meeting, March 19, 1931. Presented as a thesis in partial requirement for a Master of Arts degree from the University of Texas.

[2] Geologist, Humble Oil and Refining Company.

phy of the field and surrounding territory conforms to that of the plain, which is a monocline gently dipping southeast. The highest, lowest, and mean elevation of wells within the field are 554, 419, and 490 feet, respectively.

The area is drained by Guadalupe River and several intermittent tributaries, including Darst Creek, for which the field is named. The asphalt highway from San Antonio to Houston crosses the southwestern end of the field, making it easily accessible.

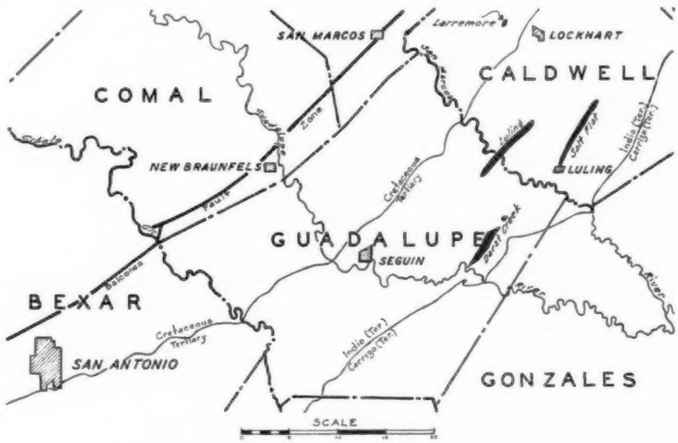

FIG. 1.—Geological and geographical location of Darst Creek field, Guadalupe County, Texas.

This article is compiled mainly from data obtained by geologists, scouts, and other employees of various oil companies to whom the writer is indeed grateful. He is especially indebted to L. T. Barrow for sponsoring this article; to L. F. McCollum for his criticisms and suggestions; to Miss Katherine Liljegren for her assistance in preparing the manuscript; and to W. E. Sanders for drafting the illustrations.

HISTORY AND DEVELOPMENT

Oil was discovered in the Darst Creek field July 18, 1929, when the Texas Company's Dallas Wilson No. 1 came in flowing pipe-line oil at the rate of 1,000 barrels per day. The field is unique in that this was the first test drilled on the structure. The fault had, however,

been previously shown on the map accompanying United States Geological Survey Professional Paper 126, by Alexander Deussen, published in 1924, and had been remapped and checked in 1928–1929 by other geologists who considered the well favorably located for testing the structure.

Upon completion of the well, operators in the area, apparently believing that the prevailing condition of over-production would soon be relieved, delayed development of the field until January, 1930. At this time an umpire took charge and invoked a systematic method of drilling and producing wells which was agreeable to all. His first schedule, issued on January 1, allowed the field a daily production of 15,369 barrels, or 68 per cent of the 22,397-barrel potential. This allowable was apportioned among the operators according to their proved 20-acre units, and the average potential production of wells in each unit. Every month, however, a small amount was deducted from the unit allowance to prorate among wells making 50 per cent or more water and to other wells affected by the resulting drainage. The daily potential increased from 22,397 barrels on January 1, to a peak of 245,864 barrels on May 1. The prolonged condition of over-production, however, caused the percentage allowable to be reduced from 68 per cent on January 1 to 9 per cent on May 1. This reduction perhaps led to dissatisfaction among operators who broke proration during the late summer and early fall of 1930. The pipe-line runs concordantly increased from a daily average of 28,201 barrels during June to a daily average of 50,763 barrels during October, and these runs hardly surpassed those of August, September, and November of the same year. As a result the Railroad Commission took control and beginning on October 29, restricted the daily allowable to 30,000 barrels. This amount remained unchanged until March 14, 1931, when it was reduced to 20,000 barrels. Then on October 17, 1931, it was further reduced to 18,000 barrels at which it remained through December, 1931.

Generally speaking, proration has been satisfactorily carried out in the Darst Creek field. It has not only kept production down but has brought about the orderly development of the field and will probably result in the ultimate production of more oil at a lower cost than would have been possible had the usual haphazard methods of development and production been followed.

Activity within the field was spurred several times by the completion of a well extending the productive area, or by one having an

exceptionally large initial production. This was particularly true when the Magnolia Petroleum Company's M. E. Roamel No. 1 came in flowing at the rate of 41,928 barrels daily, extending the field 1,500 feet northwest. Another such instance occurred when the Camp et al. Sue E. Denman No. 1 was completed as a 6,000-barrel well, extending the field one mile southwest. Several wells, notably on the Christopher Knoblock tract, had large initial productions, but their rates soon declined to normal. The condition explaining these wells is discussed in detail under Producing Horizons.

AREAL GEOLOGY

Surface beds in the Darst Creek area are Indio, or basal Wilcox, sands and sandy shales of Eocene-Tertiary age. This formation crops out in a strip of land ranging from 8 to 15 miles wide extending northeast and southwest. It may be divided into three general zones, namely, a lower sandy shale, a middle sand, and an upper sandy shale. These zones, in turn, may be locally subdivided; yet few, if any, of the subdivisions may be mapped in large areas. They either blend into one another, lense out, or change lithologic characteristics so abruptly that they can not be identified.

The field is within the upper sandy shale zone, but any subdivision of this zone is practically impossible as it is broken by the Darst Creek fault. It is evident, nevertheless, that the beds immediately northwest of the surface fault show a decided similarity to upper Indio beds which normally come in contact with the Carrizo sand, the next younger formation cropping out one mile down dip. This contact between the red sandy shale of the Indio and the deep white sand of the Carrizo reflects the structure in the field by a decided down-dip swing away from the fault, and in itself is sufficiently pronounced to incite a geologist to search toward the northwest for an explanation of it. On the southwest, where the contact swings back toward its normal position, there is an offset in it which could only be caused by a fault cutting slightly down dip. This offset definitely assures closure on the southwest end of the fault. Farther northeast, along the strike of the offset, a perfect fault exposure is found in a small ravine on the Sallie Wilson lease. This exposure shows the strata on the downthrown side of the fault dipping in toward the fault to within 2 feet of the plane. Here there is an abrupt updrag of the strata. On the upthrown side of the fault the strata dip normally southeast, excepting the 2 feet adjacent to the plane which shows an abrupt downdrag

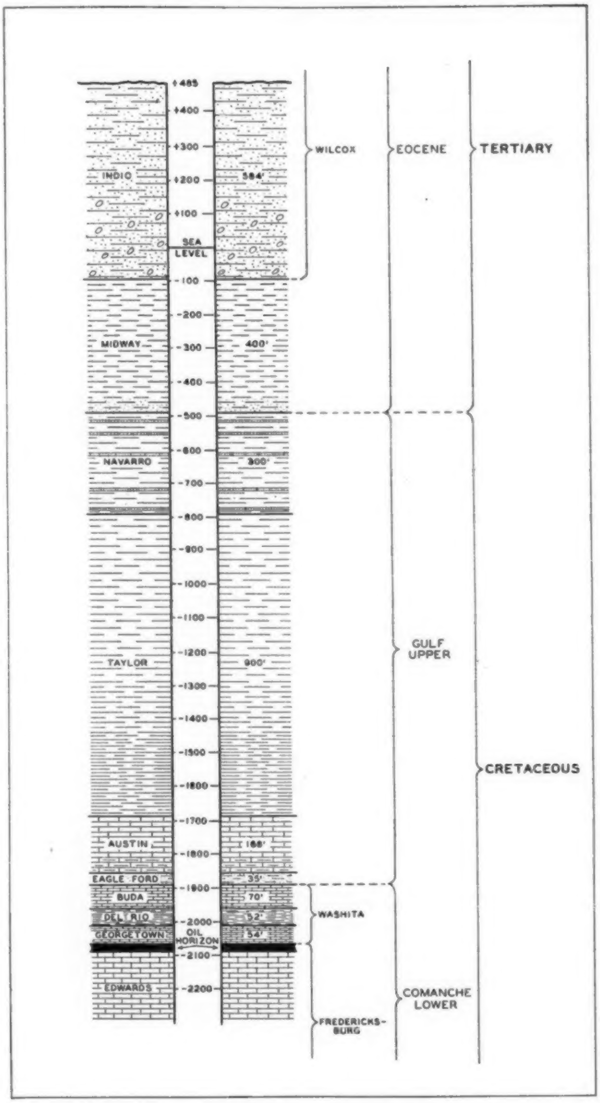

FIG. 2.—Generalized well section of Darst Creek field, Guadalupe County, Texas. Thickness of formations above Austin chalk averaged from those of several wells as determined by paleontologic laboratory of Humble Oil and Refining Company, Houston, Texas.

into the fault. The fault strikes N. 35° E. and dips 65° NW. Northeast of this exposure numerous steep dips, a repetition of beds, and several minor fractures help to place the approximate location of the surface fault. Closure on the northeast is not proved, but is strongly indicated by the up-dip swing of the Indio-Carrizo contact toward the fault plane in the vicinity of the Knodel lease. At this point, however, the Manford fault causes the contact to swing out from Darst Creek and around its own southwestern end.

The area is easily mapped. Only a few areas are covered with gravel or alluvial deposits; consequently, there are many exposures.

STRATIGRAPHY

The stratigraphic section of the Darst Creek field includes sediments from the Indio of early Tertiary age down into the Edwards, of Comanche-Cretaceous age. The upper formations of this section, namely, that part of the Indio penetrated, Midway, Navarro, and Taylor, have an average aggregate thickness of 2,100 feet. With the exception of a few boulders, these formations are usually drilled with a fishtail bit. The boulders, however, are of such induration, that it is ordinarily necessary to drill them with a roller bit. The remaining formations of Austin, Eagle Ford, Buda, Del Rio, Georgetown, and that part of the Edwards penetrated have an average aggregate thickness of 400 feet, and with the exception of the Del Rio, are drilled with a rock bit.

Despite the paucity of evidence, it is generally conceded that two and possibly three unconformities exist in the section drilled in this field. First, there is the Navarro-Midway contact, which is considered unconformable as it represents the time interval between Cretaceous and Tertiary deposition. If such an unconformity exists, however, the plasticity of the two formations has concealed the proof and left only as meager evidence an abundance of glauconite in basal Midway. Second, the Buda-Eagle Ford contact seems unconformable as it not only represents the time interval between Comanche and Gulf Cretaceous deposition, but it reveals the absence of a southwest Texas time equivalent of the Woodbine sand in northeast Texas. This condition implies that southwest Texas was probably subjected to erosion during Woodbine time, thereby resulting in an unconformity. It is believed, however, that since innumerable cores showed no evidence of this unconformity, southwest Texas was at an intermediate stage during Woodbine deposition, and neither erosion nor deposition

took place. Third, the Edwards-Georgetown contact may be proved unconformable, as evidence of a pre-Georgetown erosional surface has been discovered in Hays and Comal counties.[1] This evidence includes inliers of Georgetown, outliers of Edwards, and gravel and petrified wood supposedly in place on the Edwards outcrop. The inliers and outliers of the formations easily explain the abnormal thicknesses of the Georgetown, but as this is indefinite and as none of the other evidence has been reported from the subsurface, it is believed that the erosional surface is possibly confined to areas near the outcrop of the Edwards and Georgetown formations.

Aside from local veneers of alluvium and gravel and one small area of white sand, the surface of the Darst Creek field is covered with red sandy shales of Indio-Tertiary age. The age of the white sand is questionable, for some geologists consider it a repetition of the Carrizo on the downthrown side of the fault because of its white, coarse, and loosely consolidated character. Other geologists call the sand Indio as it is underlain by sandy shale of Middle Indio character rather than by shale and boulders of Upper Indio as would be the case if it were Carrizo. This sand is found on and near the D. D. Baker lease in the field.

The formations encountered in the Darst Creek wells are described in the following paragraphs, and with the exception of the surface formation, this description is based on the appearance of cores and cuttings from the wells.

TERTIARY

Indio.—As previously stated, the upper zone of the Indio is exposed in the Darst Creek field. The beds included in this division are composed of variegated sandy shales and boulders, which weather to brownish red and yellow color. The formation has an approximate thickness of 1,200 feet, but only 584 feet are usually penetrated by wells within the field. This thickness is not constant, however, as the surface elevation and the proximity of wells to the fault plane may alter it considerably.

The formation is highly cross-bedded and contains many traces of lignite. These characteristics indicate its deposition in shallow lacustrine or lagunal waters, and fossils in the shale and boulder horizons indicate their deposition in shallow marine waters.

[1] Presented by F. L. Whitney, department of geology, University of Texas, Austin, Texas, in a talk on Hays and Comal counties, given before a joint meeting of the Southwestern and San Antonio geological societies in October, 1931.

Midway.—Underlying the Indio sandy shales are sediments of Midway age. They consist of blue, sticky, micaceous shales and gray silts, here and there interstratified with glauconite and sand laminae. The glauconite is found in such quantities near the base of the Midway that it establishes a successful shallow horizon for correlating subsurface data. The formation has an average thickness of 400 feet, but may likewise be altered by the proximity of wells to the fault plane. The abundance of microscopic fauna and the argillaceous content of the formation suggest its deposition in a shallow epicontinental sea.

CRETACEOUS

Navarro.—Cores and cuttings from this formation reveal it to be a blue, calcareous, unctuous shale containing lenticular sand, sandstone, and arenaceous limestone. The Navarro is very similar to the underlying Taylor formation, and unless beds containing the fossil *Exogyra costata* are present in the Navarro, it is practically impossible to make a macroscopic distinction between the two. They are, however, easily distinguished microscopically. The Navarro has an average thickness of 300 feet and judged from its lithology and fossil content, seems a comparatively shallow marine deposit.

Taylor.—The Taylor consists of approximately 850 feet of massively bedded blue-gray marls and a basal chalk bed which has a maximum thickness of 50 feet. This basal bed is known as Taylor chalk and is easily mistaken for the underlying Austin chalk as both are white and have a tendency to whiten the gray color of the drill fluid. The Taylor chalk, however, is softer and may be pulverized between the finger tips.

The Taylor is likewise similar to the Austin in that each contains fault-plane cavities which serve as traps for oil which escapes from the main pay horizon and migrates up the fault plane. This condition is discussed in detail under Producing Horizons. As is the case of the Navarro, the lithology and fossil content of the Taylor indicates its deposition in a comparatively shallow sea.

Austin.—In contrast with the succession of shale and boulder beds of the overlying formations, the Austin chalk serves as the first dependable subsurface horizon marker in the field. It is a comparatively hard, white, glauconitic chalk, in places interstratified with thin beds of white marl. It contains an abundance of macroscopic and microscopic fossils, has a non-crystalline texture, and is composed of approximately 80 per cent calcium carbonate. Although it is in many

places stained with oil, the chalk does not produce in the field excepting from fault-plane cavities. These cavities are discussed in detail under Producing Horizons. The chalk has an average thickness of 168 feet. It is a typical marine formation, deposited in moderately deep warm waters.

Eagle Ford.—There are two distinct types of Eagle Ford shale encountered in the Darst Creek field, namely, jet-black, thinly laminated, lignitic shale, and gray, thinly laminated, arenaceous shale. Both types are fossiliferous, and almost invariably present a rich showing of oil where penetrated. Many tests, however, have proved this showing valueless. The formation has a fairly uniform thickness of 35 feet throughout the field, and judged from its inclusion of animal and plant remains, it seems to be the near-shore phase of a marine deposit.

Buda.—The Buda is hard, white, dense, and fairly crystalline limestone. Although it resembles the Austin chalk in some respects, they may be distinguished by the following criteria: (1) the Buda is much harder; (2) it is characterized by a scattering of blue-black specks, whereas the chalk is characterized by an abundance of green glauconitic specks; (3) the Buda has a characteristic manner of fracturing into square corners, whereas the chalk has not; (4) the Buda contains scarcely any macroscopic fossils, whereas they are plentiful in the chalk; and (5) the Buda is much more dense, brittle, and crystalline than the chalk.

The formation has an average thickness of 70 feet, and is regarded as of true marine origin.

Del Rio.—With the exception of several thin layers of *Exogyra arietina* agglomerate, the Del Rio is composed of blue-gray plastic clays. It is entirely different from the overlying and underlying limestone formations; yet its subsurface contact with the two is very difficult to place. This is because the upper and lower parts of the formation are sufficiently hard and compact to drill like limestone whereas only the middle 20 or 25 feet of the formation drills like clay. It is necessary, therefore, to determine the formation contacts from cuttings. The Del Rio has an average thickness of 52 feet, and is considered a comparatively shallow marine deposit.

Georgetown.—This formation consists of alternating beds of hard, blue-gray limestone and somewhat thinner beds of calcareous clays. It is richly fossiliferous, containing many macroscopic and microscopic fossils, for example, *Kingena wacoensis*, *Alectryonia carinata*,

and *Gryphaea washitaensis.* Although the Georgetown serves as the impervious layer overlying the pay horizon, operators take no chance of water seeping in and set casing as near as possible to its base. The formation, which has an average thickness of 54 feet, was laid down in near-shore waters of a sea into which clays were washed and deposited along with the limestone.

Edwards.—The Edwards formation, the main producing horizon in the field, is composed of a series of hard, crystalline, dolomitic limestones interspersed with lentils and nodules of chert. The upper part of the formation, known as "dobe," is so extremely porous and soft that a roller bit merely sinks through it. The chert, however, is so hard that it easily wears out a set of roller-bit cones in an 8- to 10-inch penetration. As 4 wells grouped closely around the Texas et al. Wilson Heirs (Jarmon) No. 1 encountered practically the same thickness of chert at approximately the same subsurface depth, and as the chert could not be correlated over long distances, it seems evident that the chert is lenticular. Because of this fact, and because some wells showed water without penetrating any lentils and other wells did not show water after penetrating four lentils, it is believed that the lentils have little or no control over the oil-water level. Several wells, in fact, had to be drilled through several lentils in order to obtain a reasonable initial production.

Although the Edwards is approximately 700 feet thick, the average penetration of wells is only 28 feet. The maximum penetration is by wells in the middle of the field and amounts to 55 feet. The purity of the limestone and the presence of corals and other fossils in it indicate its deposition in warm marine water.

STRUCTURE

As indicated by the areal geology, subsurface well data have proved that the Darst Creek field resulted from a faulted monocline. The maximum displacement along the fault is calculated on top of the Austin chalk to be approximately 550 feet. This displacement was computed from the Stroube and Stroube Mrs. L. G. Denman No. 1, which was abandoned at 2,192 feet below sea-level without encountering the chalk, and the Humble Oil and Refining Company's Mrs. L. G. Denman No. 23, which encountered the chalk at 1,649 feet below sea-level, or 543 feet higher than the depth at which the Stroube well was abandoned. The displacement is ordinarily in one break (Fig. 4); but in several areas it is known to be divided into at least

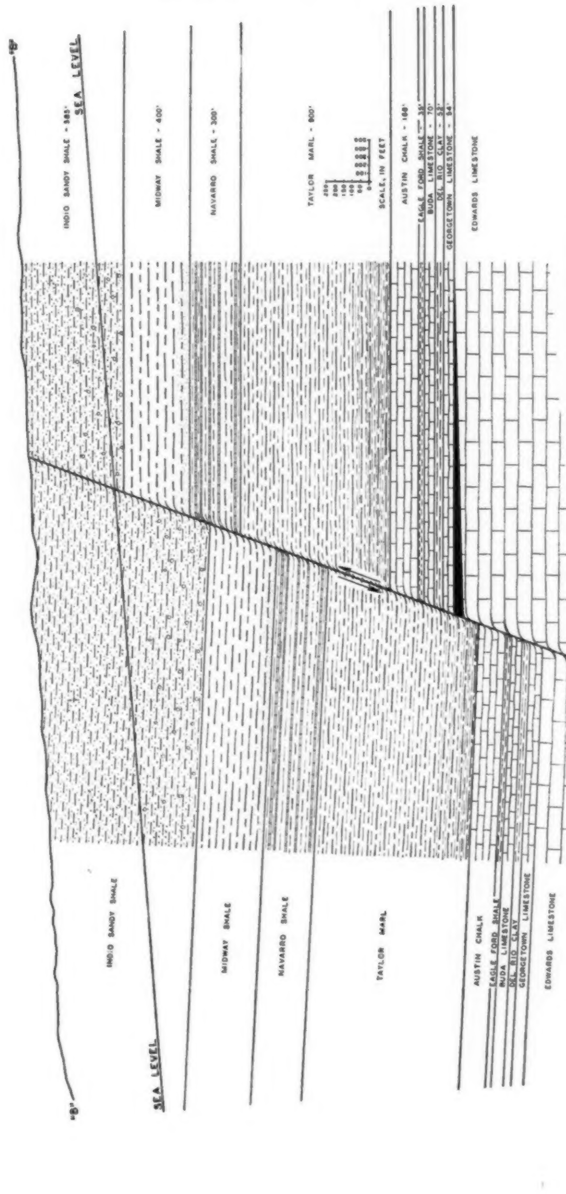

FIG. 3.—Cross section *B-B* (Fig. 7), Darst Creek field, Guadalupe County, Texas.

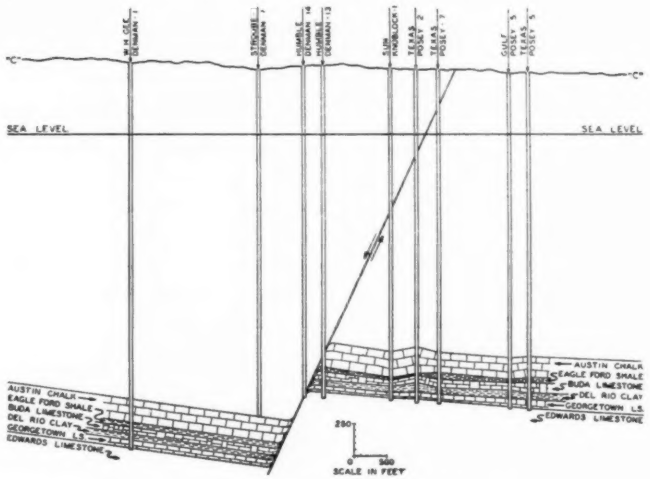

FIG. 4.—Cross section *C–C* (Fig. 7), Darst Creek field, Guadalupe County, Texas.

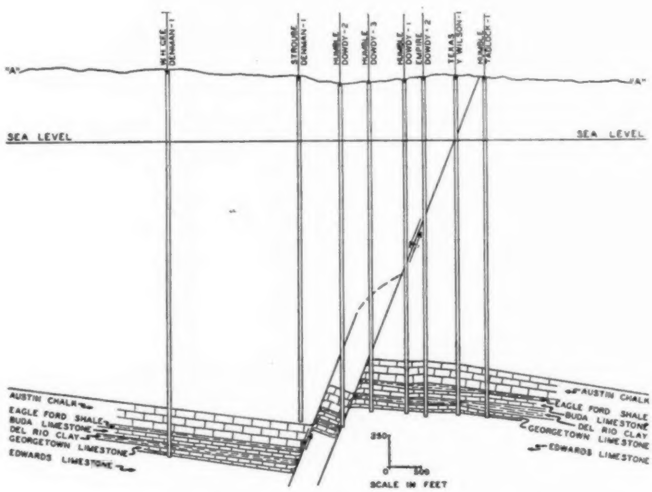

FIG. 5.—Cross section *A–A* (Fig. 7), Darst Creek field, Guadalupe County, Texas.

two breaks (Fig. 5). These areas were proved by the Hager et al. Bibbs No. 1, and the Humble Oil and Refining Company's Dowdy No. A-2, both of which encountered practically full sections of Austin chalk approximately 275 feet higher than normal downthrown chalk, but 275 feet lower than normal upthrown chalk. As the displacement of the fault is known to approximate 550 feet in some areas, it is logical to assume that either the 550-foot displacement has decreased to 275 feet in the Bibbs and Dowdy areas, or that it is divided between two faults, each having an approximate displacement of 275 feet. This latter explanation seems more logical not only because the Humble Oil and Refining Company's Dowdy No. A-3 was approximately 275 feet higher than the Humble's Dowdy No. A-2, which in turn was approximately 275 feet higher than the Stroube and Stroube Mrs. L. G. Denman No. 1 (Fig. 5), but also because the Bibbs area is located just opposite the highest area in the field, and it is not logical to assume there is a 275-foot fault opposite this area when there is a 550-fault foot opposite structurally lower areas. The only other areas where the fault displacement seems divided are on the northeast and southwest extremities of the field. At these points it seems only natural that minor fractures have broken from the main fault and partly account for its diminishing displacement. Just beyond the northeast extremity of the field, the main fault splits, one continuing N. 48° E. for an indefinite distance, and the other turning N. 70° E., passing through the Appling and Echols areas, and explaining the producing crevice wells there.

The Darst Creek fault is normal with its upthrown side on the southeast. It dips 65° NW. and, beginning at the extreme southwestern end of the field, its strike varies little from N. 35° E. for a distance of 5 miles. At this point it cuts down dip forming the northeast closure of the field. Closure is formed on the southwest by the down-dip strike of the fault gradually making the area too low structurally to produce. It is formed on the northwest by the abutment of the pay horizon with impervious marls at the fault plane, and on the southeast by the regional Edwards dip of 220 feet per mile.

There are three main reasons for believing the Darst Creek structure resulted from the subsidence of the downthrown side of the fault, rather than from the uplift of the upthrown side.

1. If the field had been faulted up, the dip of the formations on the upthrown side would be materially steeper than the dip of the formations in the surrounding area. This is not the case; in fact, with

the exception of the southwestern end of the field, the 220-foot per mile dip of the Darst Creek formations is slightly flatter than that of the surrounding area. The accentuated dip on the southwestern end of the field (Fig. 6) is required by the subsurface information from several fairly low wells and one extremely low well. It is believed, however, that the extremely low well, and consequently the plunging-off on the southwestern end of the field, is possibly due to a crooked hole, but probably to the location of the well on the downthrown side of a small fault. This fault may be entirely separate from the Darst Creek fault, or it may have split from the Darst Creek fault in the vicinity of the Camp et al. Sue E. Denman No. 1 well.

2. Three or more wells have encountered the basal 300-foot section of downthrown Taylor marl and proved that this section is much harder than the same section of upthrown Taylor. This hardness may be explained only by metamorphism incurred from the heat and pressure accompanying movement, and as the upthrown side shows little or no metamorphism, it is assumed that the upthrown side did not undergo movement. Wells which furnished this information are Camp et al. Sue E. Denman No. 1, Empire Gas and Fuel Company's Chris Knoblock No. 3, Humble Oil and Refining Company's Mrs. L. G. Denman No. 13, and others.

3. Regardless of whether the downthrown side subsided or the upthrown side was uplifted, it would seem that neither would do so regularly throughout a very large area. In fact, local areas varying in power to resist the movement would cause innumerable "highs," "lows," and faults on the side which was moved. As the writer believes this would be the case, and as wells have proved the regularity of the upthrown side, it is assumed that the downthrown side is irregular and that its subsidence caused the Darst Creek structure.

The age of the structure is known only to be later than Carrizo-Tertiary time.

PRODUCING HORIZONS

Although wells in the Darst Creek field produce from three distinct horizons, it is believed that all of the oil is from the same source.

1. *Edwards limestone.*—The oil is found in the upper porous zone of this formation which is the main producing horizon in the field. With the exception of an area on the Christopher Knoblock tract, this upper zone maintains a fairly uniform porosity throughout the field. On this tract, however, six wells came in with exceptionally

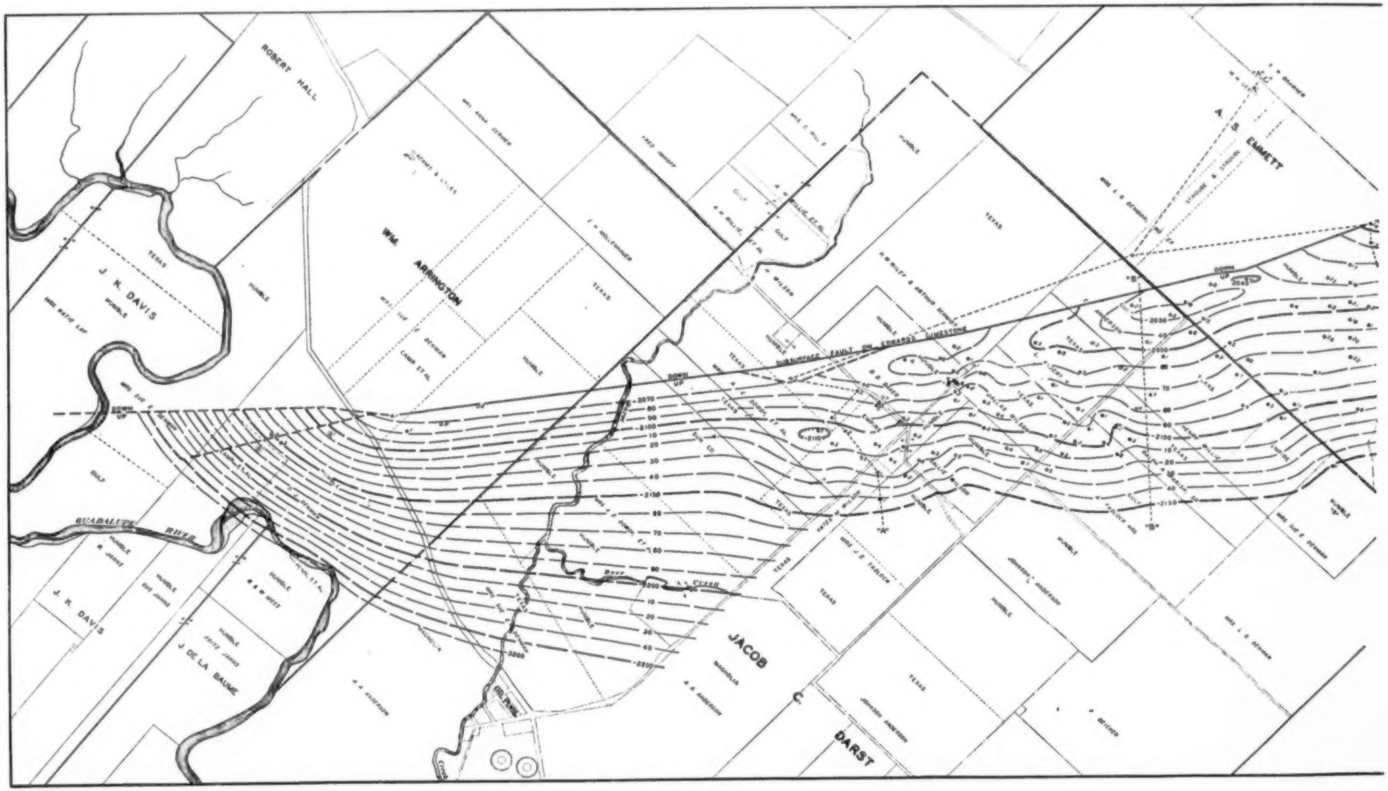

FIG. 6 (Left half)

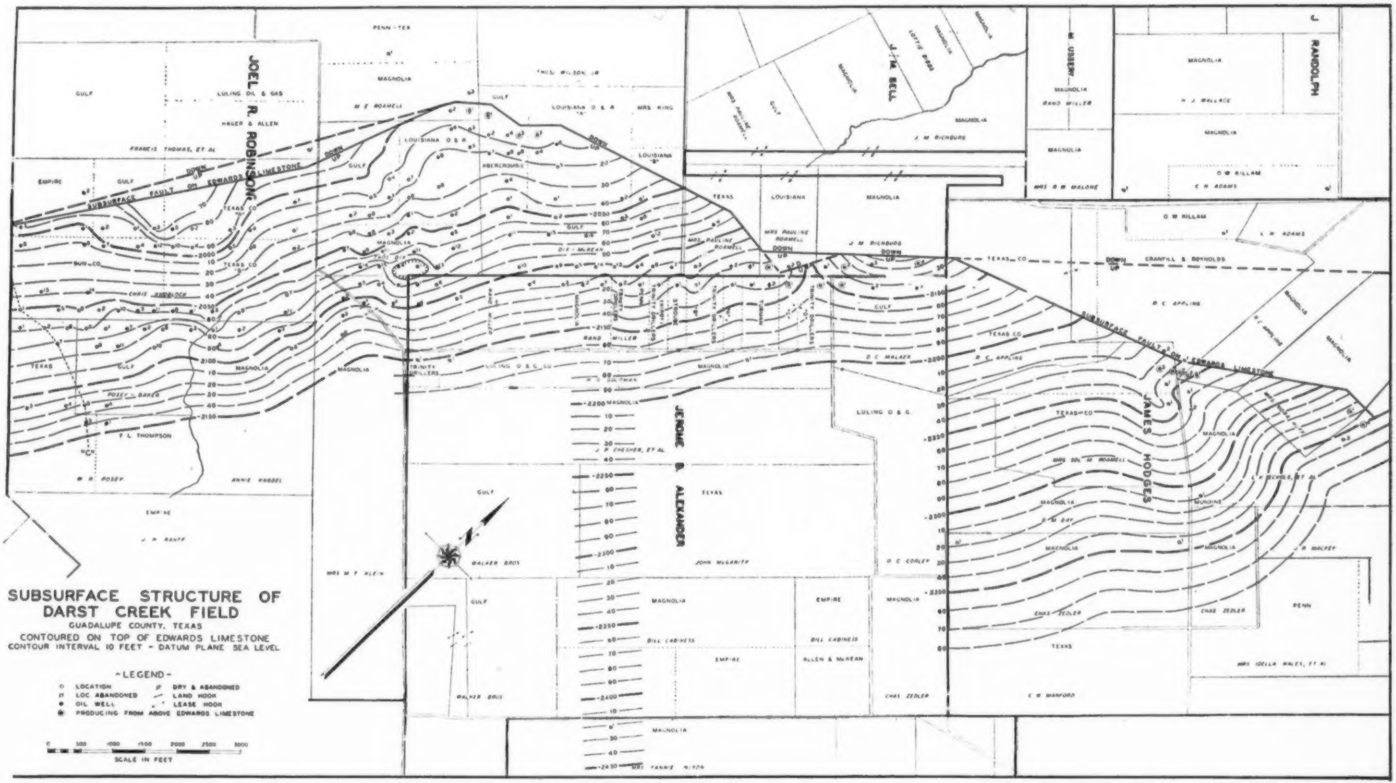

Fig. 6 (Right half)

large initial productions, and were attributed to additional porosity or to small complex fractures in the pay horizon, rather than to a connection with the main fault plane as enlarged initial productions are usually explained.

2. *Taylor and Austin formations.*—Oil-producing cavities were formed in the non-plastic, metamorphosed Taylor marl and Austin chalk by the main fault; and as both formations are impervious, each is capable of sealing the cavities and trapping the oil which escapes from the Edwards limestone and migrates up the fault plane. The nineteen wells which have produced from cavities seem to be confined to minor faults which split from the main fault at the extremities of the field, or to the main fault where it makes abrupt changes in strike. It is interesting to note that most of the wells drilled into these cavities have a large initial production, though some get only a showing of oil, and a few are dry. This, of course, depends on the size of the cavity, the amount of oil trapped therein, and the hydrostatic pressure.

It is necessary to take extra precautions with cavity wells which have a large initial production as their rate of flow is not due to an unlimited supply of oil, or to gas which causes the oil to flow rapidly, but to the hydrostatic head. The water, being less viscous, tends to cone the oil aside, thereby disturbing the oil-water level and ultimately destroying the well. This may be prevented, however, by choking the well to a steady moderate flow, thus leaving the oil-water level undisturbed. By confining these wells to a steady moderate flow, they are likely to produce more oil than normal Edwards wells, and after cavity production has ceased, wells located high enough on the structure may be deepened to the Edwards for additional production.

3. *Serpentine.*—Two wells are supposedly producing from the reworked serpentine deposits encountered on the extreme northeast end of the field in an area where at least four additional wells encountered serpentine. It is believed, however, that these wells produce from cavities not only because they are located on the end of the field where minor faults split from the main fault, but because the serpentine encountered was hard, dry, and reworked.

The chief significance of the serpentine is that it is probably indicative of a near-by plug. It was deposited during Austin chalk or early Taylor time.

SOURCE OF OIL

As the character of the oil from the three horizons is practically the same, it is thought to be from the same source. Four main theories have been advanced to account for its origin: (1) the oil originated in some deep-seated beds, later migrating up the fault plane into its present position within the upper Edwards limestone; (2) the oil originated in the downthrown petroliferous Eagle Ford shale, later migrating across the fault plane into the abutting Edwards; (3) the oil had its origin in downthrown Taylor marl which was faulted in juxtaposition with the Edwards limestone into which it migrated; and (4) the oil is indigenous to the Edwards limestone. All these theories have been discussed in previous papers,[1] and each of the last three has considerable merit. The writer's preference, however, is that the oil is indigenous to the Edwards limestone. This preference is based on the fact that the oil is found in the Edwards limestone, and that there have been numerous reports of asphaltum and other bituminous matter found in the surface outcrop of the Edwards. As further corroboration, Richard Jones makes the following statement.[2]

> An interesting feature of the analysis is that the main pay zone beneath the "dobe" contains 20.6% of organic material. Oil originates from decomposed organic matter, both of plant and animal nature; and the analysis shows that in the Salt Flat Field organic material comprises one-fifth of the producing limestone, a significant fact.

OIL, GAS, AND WATER DATA

The Darst Creek field produced a total of 19,700,340 barrels of pipe-line oil through December, 1931. The field has a total of 1,670 proved productive acres which have yielded an average of 11,797 barrels of oil per acre. This yield per acre seems low in comparison with the 26,294-barrel yield per acre for the Luling field, and the 20,677-barrel yield per acre for the Salt Flat field, but this low yield is due to the youth of the Darst Creek field. The Luling field had been producing approximately 7 years, and the Salt Flat field approximately 1 year when the Darst Creek field came in. Furthermore, the

[1] L. F. McCollum, C. J. Cunningham, and S. O. Burford, "Salt Flat Oil Field, Caldwell County, Texas," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 14, No. 11 (November, 1930).

Ernest W. Brucks, "The Luling Field, Caldwell and Guadalupe Counties, Texas," *ibid.*, Vol. 9, No. 3 (May–June, 1925).

[2] Richard Jones, "Surface and Subsurface Characteristics of the Edwards Limestone," *Oil Weekly* (September, 1931), p. 19.

Luling and Salt Flat fields are fully developed, whereas the Darst Creek field is not yet completely developed. It is the opinion of the writer, however, that Darst Creek will ultimately produce 35,000 barrels of oil per acre, and exceed the estimated yield per acre of the Luling and Salt Flat fields. This estimated excess is primarily due to the improvement of drilling and production methods since the Luling field was developed, to the more orderly development of the Darst Creek field than of the Luling and Salt Flat fields, and to a thicker "pay" at Darst Creek than at Salt Flat. Considering the total of 1,670 proved acres and the estimated yield per acre, Darst Creek

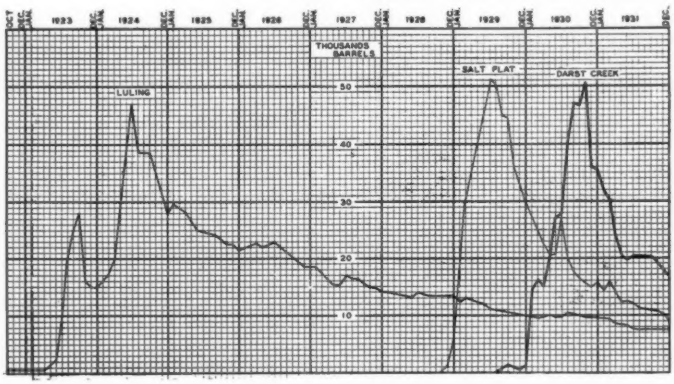

Fig. 7.—Daily average production curves for Luling, Salt Flat, and Darst Creek fields, Caldwell and Guadalupe counties, Texas.

should have an ultimate production of 58,450,000 barrels. The oil from the field has a deep green color, an average gravity of 36° Bé., and a paraffine base.

Some of the oil, ordinarily in the form of an emulsion, requires a simple treatment with a commercial treating compound before being accepted by pipe-line companies. There are four pipe-line companies serving the field with a combined capacity of 58,000 barrels daily.

The price of the oil has varied from \$0.20 per barrel during part of July, 1931, to \$1.15 per barrel during April, 1930. The present, January, 1932, price is \$0.60 per barrel.

Gas containing a small percentage of H_2S is associated with the oil, and along with the hydrostatic pressure, accounts for the initial flowing of wells. On the basis of an equal development in all parts of

the field, the central and western parts flow much longer than the eastern. This is due to a thicker "pay," to perhaps a greater penetration of the "pay," and to more gas associated with the oil in these parts. Western edge cavity wells flow chiefly because of the hydrostatic pressure behind the oil, and because of the absence of any obstacle to prevent the upward migration of the oil.

TABLE I*

ANALYSIS OF CRUDE OIL FROM THE TEXAS COMPANY'S DALLAS WILSON NO. 1, DARST CREEK FIELD, GUADALUPE COUNTY, TEXAS

Gravity, A.P.I. at 60°F.	36.7°
Water and sediment by centrifuge, by volume (ASTM D96-28)	0.1 per cent
Water by volume (ASTM D95-28)	Trace
Sulphur by weight (ASTM D129-27)	0.78 per cent
Color	Dark green
Pour point, F. (ASTM D97-28)	30°
Say. Univ. Viscosity at 30°C. (86°F.)	51
Say. Univ. Viscosity at 40°C. (104°F.)	46
Say. Univ. Viscosity at 50°C. (122°F.)	43

Distillation yields:

	Temp. °F.	*Per Cent*	*Grav. °A.P.I.*	*Flash °F.*	*Fire °F.*	*Pour Point °F.*	*Saybolt Univ. Vis. at 100°F.*
Gasoline	397	23.3	58.2				
Kerosene	496	15.0	44.7	162	182		
37-40 distillate	528	5.0	40.5	215	245		
Residue		55.7	26.8	310	350	65	242 Sec.
Loss		1.0					
		100.0					

Color of residue, dark green

* Analysis through courtesy of A. W. Weeks, Shell Petroleum Corporation, San Antonio, Texas.

TABLE II

DARST CREEK PIPE-LINE OUTLETS

Company	*Size (Inches)*	*Capacity (Barrels)*	*Terminal*
Gulf Production Co.	6	10,000	Crosby, main line to Port Arthur
Humble Pipe Line Co.	6-8	24,000	Luling tank farm
Magnolia Petroleum Co.	4	9,000	Luling tank farm
Texas Pipe Line Co.	6	15,000	Rosanky, main line to Port Arthur
Total		58,000	

Shortly after completion, some of the wells produce sulphur water. This is probably due to the non-constant oil-water level which has a tendency to conform to structure, rather than to an established subsurface depth, and to operators drilling wells too deep into the pay horizon seeking a large initial production. A late oil-water production ratio is not available, but the proration umpire report of November,

1930, shows the 230 wells within the field had a daily potential of 228,733 barrels of fluid, of which 72,929 barrels was sulphur water.

It is interesting to note that in a study[1] of ten samples of water taken throughout the field there is a slight difference in the chemical composition of bottom and edge waters. This difference is mainly that bottom water shows a similarity to sea water, whereas edge water shows more similarity to altered connate water. In bottom water the ratio of the chloride (R.V.) to the sulphate and carbonate (R.V.) is 9.38, whereas in 77 different analyses of sea water the ratio averaged 9.35. Edge-water analyses showed the chloride to sulphate and carbonate ratio (R.V.) to be almost double the same ratio in bottom water. A sample of water from a crevice well within the field proper showed practically the same ratio and chemical composition as the samples of bottom water. A sample of water from a crevice well in the Appling area, however, was entirely different from any other type of water within the field.

TABLE III*

ANALYSIS OF WATER FROM EMPIRE GAS AND FUEL COMPANY'S MRS. A. E. DOWDY NO. 2, DARST CREEK FIELD, GUADALUPE COUNTY, TEXAS

Radical	*Parts per Million*	*Comparison Data*		*Ratios*	
Sodium	6,538	Primary salinity	76.26	Chloride: bicarbonate	21.9
Calcium	1,000	Secondary salinity	19.40	Bicarbonate: sulphate	13.
Magnesium	470	Primary alkalinity	0.00	Calcium: magnesium	1.29
Chloride	12,600	Secondary alkalinity	4.34	Sodium: calcium and magnesium	3.21
Sulphate	60	Chloride salinity	99.7		
Bicarbonate	988	Sulphate salinity	0.3		
Carbonate	—				
Total	21,656				
Hydrogen sulphide	406				

* Analysis by the Humble Oil and Refining Company laboratory, Houston, Texas.

DRILLING AND PRODUCING METHODS

The similarity between the Darst Creek and Salt Flat fields enabled Darst Creek operators to use a type of drilling equipment similar to that used in Salt Flat. A 21-inch rotary, 11×11 or 12×12 twin-cylinder drilling engine, 6-inch 3-speed draw works, two 66-H.P. boilers, and two 12×6¾×16-inch slush pumps are considered average equipment. Derricks 96 feet in height and reinforced by relegs are used to drill the wells, the relegs being used on successive wells. After

[1] Correlation of Luling, Salt Flat, and Darst Creek waters by S. L. Bishkin, Humble Oil and Refining Company laboratory, Houston, Texas.

wells are completed, derricks are left standing so that they may be used when the wells are put on the beam. A string of 4-inch drill pipe with 2 joints of 6-inch pipe on the bottom is in almost universal use.

Usually, two 21-foot joints of 10-inch casing are cemented with 25 sacks of cement in a 13⅜-inch hole for surface casing. A 9⅞-inch hole is then carried down to approximately 2,600 feet or as near to the base of the Georgetown limestone as can be judged from cuttings. A string of 7-inch O.D. pipe is set at this depth and cemented with 100 sacks of cement. After drilling into the Edwards a 2½ or 3-inch string of tubing is set close to bottom through which the oil is produced. There is no perforated liner or screen set in the wells as the producing horizon does not cave or crumble. An average of 2 or 3 weeks is necessary to complete the wells. Practically all the wells are pumped by Lufkin, Nutall, or Allis-Chalmers units; however, a Lufkin 5½-inch Herring-bone unit driven by a 35–55-H.P. electric motor, through the medium of a V-belt drive, is the most common hook-up. Electric energy is supplied by the Central Power and Light Company. Necessary water for field operations is obtained from the Guadalupe River.

FUTURE DEVELOPMENT

As the extent of the field has been practically defined by dry holes, there is little chance for an increase in the number of productive acres.

Even though some parts of the field have been intensively drilled, there is still an average of 6.1 acres per producing well. In view of the restricted outlet, the prevailing low price of crude, and the general depressed condition of the oil industry, it is not probable that future development will reduce this average to less than 5 acres per well.

DISCUSSION

F. H. Lahee, Dallas, Texas: I think it is well worth while calling to the attention of those who favor vertical migration of oil from unknown deeply buried sources Mr. McCallum's remarks on the improbability of the Darst Creek oil having ascended from any source stratigraphically lower than the Edwards limestone in which it now occurs.

BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
VOL. 17, NO. 1 (JANUARY, 1933), PP. 38-51, 2 FIGS.

PRE-TERTIARY ROCKS FROM DEEP WELLS AT JACKSON, MISSISSIPPI[1]

WATSON H. MONROE[2]
Washington, D. C.

ABSTRACT

The gas at Jackson, Mississippi, is produced from hard, porous limestone between the Selma chalk (Upper Cretaceous) and the Porters Creek clay of the Midway group (Eocene). Minor structural features of the gas-producing horizon are determined by the topography of an old erosion surface at the top of the Selma. Directly underlying the Selma chalk is the Tuscaloosa formation which contains volcanic and intrusive material in its lower part. This igneous activity took place early in Tuscaloosa time, probably at approximately the same time as that in Arkansas, which suggests that the lower part of the Tuscaloosa is equivalent to part of the Woodbine sand.

Underlying the Tuscaloosa formation is a series of hard, steeply dipping rocks that are considered to be of Carboniferous age on the evidence of plant material and close lithologic similarity to rocks of the Pottsville formation which crop out near Tuscaloosa, Alabama.

Discovery of steeply dipping Paleozoic rocks at Jackson suggests that the belt of Appalachian folds passes through Mississippi near this point.

INTRODUCTION

Location.—The Jackson gas field, in Hinds and Rankin counties, Mississippi, is located in and near the city of Jackson in the eastern Gulf Coastal Plain, about 160 miles north of New Orleans and 40 miles east of Mississippi River at Vicksburg. The structure and the rocks of the field down to and including the Selma chalk are described in *U. S. Geological Survey Bulletin 831-A*, which was issued in March, 1932.

Acknowledgments.—The coöperation given by oil companies has greatly aided in the preparation of this paper. Thanks are due especially to officials of the Gulf Refining Company of Louisiana, the United Gas Public Service Company, and The Texas Company for core samples and for permission to publish information derived from their study.

General stratigraphy.—Most of the wells have not been drilled below the gas horizon between the Porters Creek clay and the Selma

[1] Read before the Association at the Oklahoma City meeting, March 24, 1932. Manuscript received, July 14, 1932. Published by permission of the director, United States Geological Survey.

[2] United States Geological Survey.

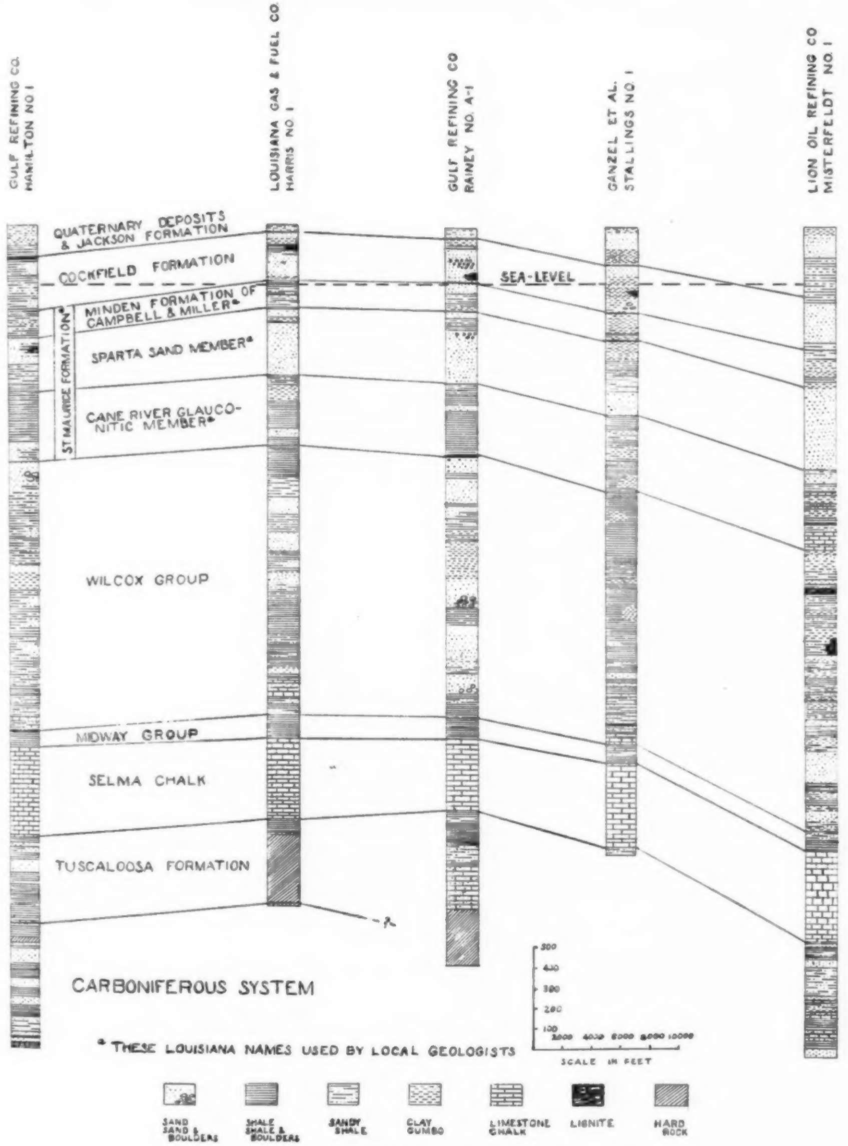

FIG. 1.—Graphically platted and correlated logs of deep wells.

TABLE I

Correlation of Formations at Jackson, Mississippi
(Thickness in Feet)

Age		Parts of Louisiana and Arkansas			Jackson, Mississippi		Northern Mississippi		
TERTIARY	Eocene		Jackson formation 525–575			Jackson formation 440±		Jackson formation 150–600	
		Claiborne group	Cockfield formation 375–1,000		Claiborne group	Cockfield formation 220±	Claiborne group	Cockfield formation 30–400	
			St. Maurice formation*	Marine marl* 130 (Minden fm. of Campbell and Miller)		Marine marl 120±		Lisbon formation	Marine marl 50±
				Sparta sand* member 600–692		White sand 350–400			Kosciusko ss. member 0–50+
				Cane River glauconitic member* 235–537		Glauconitic sand and clay 330–390			Winona sand member 45–300±
								Tallahatta formation 15–240	
			Wilcox group 780–1,798			Wilcox group 1,310–1,375	Wilcox group	Grenada formation 60–250	
								Holly Springs sand 160–600	
								Ackerman formation 300–550	
			Midway formation 673–799±		Midway group	Porters Creek clay 75–125	Midway group	Porters Creek clay 75–200	
						Clayton (?) limestone† (?)		Clayton formation 0–60	
CRETACEOUS			Arkadelphia clay					Ripley formation 100–400	
			Nacatoch sand			Absent (?)			
			Saratoga chalk						
			Marlbrook marl						
			Annona chalk 20–100			Selma chalk† 340–440		Selma chalk 250–900	
			Ozan formation						
			Brownstown marl						
			Tokio formation			Absent		Eutaw formation 250–550?	
			Woodbine sand			(?) Tuscaloosa formation 400+		Tuscaloosa formation 200–1,700±	
			Trinity formation			Absent		?	
CARBONIFEROUS			?			Shale and sandstone, possibly of Pottsville age 600+		?	

* These Louisiana formation names have been used at Jackson by petroleum geologists.
† It has not been determined whether the gas rock is of Selma or of Clayton age.

chalk, but some wells have been drilled deeper and 11 wells have entered beds underlying the Selma chalk. Graphically plotted logs and their correlations for 5 of the wells that have penetrated pre-Selma rocks to appreciable depths are shown in Figure 1.

The formations penetrated above the Selma as well as below the Selma are shown on the correlation chart (Table I). In the Tertiary there are two readily recognizable horizons—the base of the sand correlated with the Sparta sand member of the St. Maurice formation and the top of the Midway group.

The gas rock is hard, porous, very fine limestone, having an average thickness of nearly 4 feet. Although its age is not certainly known, most observers believe it to be Upper Cretaceous (upper Selma), but recently evidence has been presented that it may be Tertiary (Clayton, Midway). L. W. Stephenson[1] examined a specimen of the gas rock from Meredith and Smith's Strawder No. 2 well, in Sec. 12, T. 5 N., R. 1 E., Rankin County, sent to the Geological Survey by Robert L. Steffey, Jackson, Mississippi. Stephenson's report on this specimen follows.

> The rock contains the internal and external molds of many fossils. The most abundant form is a small *Meretrix*-like shell belonging in the family Veneridae; this shell is plump with strong concentric sculpture and is probably an undescribed species. A fragment of an echinoid, presenting an interior view, and an echinoid spine are scarcely adequate for identification. The small apical portion of a *Turritella* has not as yet been matched with any known species. One small *Natica*-like gastropod and a small fragment of a crustacean were observed. No organism suggestive of the Cretaceous age of the rock was observed. Both the lithology and the fauna appear to me to be more suggestive of Tertiary than Cretaceous.

The Porters Creek clay, of the Eocene series, is underlain by the gas rock, which in turn is underlain by Selma chalk. Underlying the Selma is a series of red, brown, and white sand and clay, referred to the Tuscaloosa formation. The Ripley formation, which, if present, would overlie the Selma, and the Eutaw formation, which normally underlies the Selma, are wanting on the Jackson anticline. Unless they are represented by parts of the chalk they were either never deposited or were eroded away subsequent to their deposition.

The Tuscaloosa formation is underlain unconformably by hard gray calcareous sandstone and black, gray, and pink shale. The lithologic aspect of these rocks, particularly the sandstones, indicates

[1] L. W. Stephenson, memorandum to W. H. Monroe, July 6, 1932.

that they represent rocks of the Carboniferous system, which crop out in the Appalachian region from Tuscaloosa, Alabama, northward. This correlation is confirmed by Carboniferous fossil plant material found in core samples. There are numerous dikes, stocks, and sills of igneous rocks cutting the Carboniferous and Tuscaloosa formations.

Structure.—The structure of the Jackson anticline is plainly shown by the surface distribution and dips of the rocks. The Cockfield formation, of the Claiborne group, is exposed in the city of Jackson but is surrounded by the outcropping beds of younger formations. The contact of the Cockfield with the overlying Jackson formation dips away from the city in every direction. The approximate axis of the Jackson anticline pitches north-northeast as far as Madison Station, 11 miles from Jackson, in the southern part of Madison County, where the normal southwest regional dip is resumed. As shown by use of the contact between the Cockfield and Jackson formations as a key horizon, the crest of the anticline at Jackson rises approximately 300 feet higher than the bottom of the saddle at Madison Station. There is, therefore, a closure of 300 feet in the structure.

The top of the gas rock is commonly used to determine subsurface structure and as shown on the structure map (Fig. 2) it is characterized by five major structural "highs" with smaller "highs" on their flanks. There is a suggestion of a possible sixth dome in Sec. 8, T. 5 N., R. 2 E., but this area has not yet been explored.

The Jackson anticline probably originated early in Tuscaloosa time. The deformation was accompanied by intrusion of igneous rocks, and was supplemented by successive periods of uplift at various times up to the middle of the Miocene. Compaction of sediments around the buried hill of igneous and sedimentary rocks has probably contributed to the relative upward-doming of the Tertiary formations.

The irregular surface of the gas rock seems to be due to erosion of the top of the Selma chalk supplemented by folding. At the beginning of the long erosion period following deposition of the Cretaceous formations the Jackson area was again deformed. Erosion immediately began, completely removing the Ripley formation, or whatever beds may have represented it, and carving deep valleys that to-day form the unproductive structural "lows" on the top of the general structure. Because of this erosion on top of the general structure the Selma chalk is much thinner in wells drilled there than in wells on the sides; for example, in the Gulf Refining Company's Rainey No. A-1 gas well on the anticline it is 348 feet thick, but in the

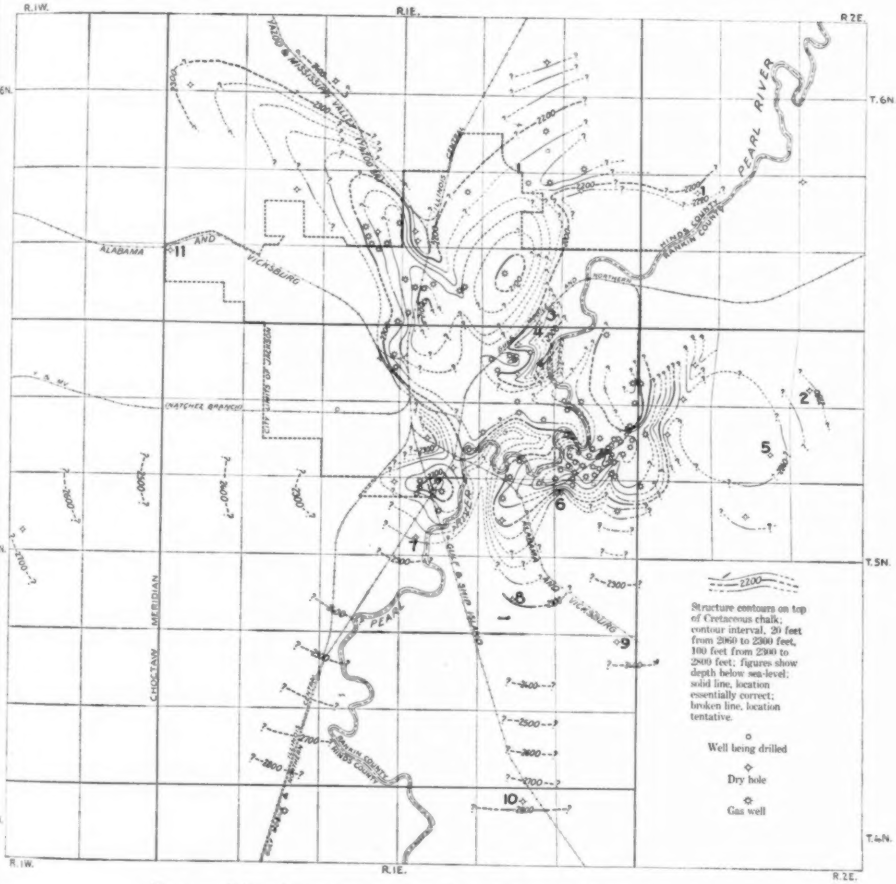

FIG. 2.—Subsurface structure map of Jackson gas field, Mississippi.

TABLE II

WELLS ENTERING BEDS UNDERLYING SELMA CHALK

No.	County	Sec.	T.N.	R.E.	Operator	Lease and number	Top Selma (Ft.)	Top Tuscaloosa (Ft.)	Top Igneous (Ft.)	Top Pottsville (Ft.)	Total Depth (Ft.)	Rocks at Total Depth
1	Hinds	30	6	2	Gulf Ref. Co.	McLaurin No. 1	2,485	2,874	2,935	—	2,950	Igneous rock
2	Rankin	4	5	2	Gulf Ref. Co.	Hamilton No. 1	2,563	2,998	3,268	3,418	4,027	Igneous rock
3	Hinds	35	6	1	Jackson O. & G. Co.	Taylor No. 1	2,545	?	2,915?	?	3,232	Igneous rock
4	Hinds	35	6	1	Louisiana Gas & Fuel Co.	Harris No. 1	2,506	2,904	2,975	3,227	3,239	Carboniferous and igneous
5	Rankin	8	5	2	U. Gas Pub. Ser. Co.	McLaurin No. B-1	2,515	2,937	?	?	3,296	Perhaps Carboniferous
6	Rankin	13	5	1	Gulf Ref. Co.	Rainey No. A-1	2,500	2,847	2,996	—	3,607	Igneous rock
7	Hinds	15	5	1	Cane River O. & G. Co.	Kabbes No. 1	2,542	2,885?	—	—	3,270	Tuscaloosa
8	Rankin	23	5	1	Gulf Ref. Co.	Hanna No. 1	2,564	2,933	3,070?	3,165?	3,887	Carboniferous
9	Rankin	25	5	1	Ganzel et al.	Stallings No. 1	2,628	3,035	—	—	3,071	Tuscaloosa
10	Rankin	2	4	1	Lion Oil Ref. Co.	Misterfeldt No. 1	3,064	3,502	—	—	4,075	Tuscaloosa
11	Hinds	31	6	1	Marine O. & G. Co.	Country Club No. 1	2,710	?	2,992?	—	3,063	Igneous material

Gulf Refining Company's Hamilton No. 1 well, a dry hole 2 miles east of the producing area, off the anticline, it is 435 feet thick, and in the Lion Oil Refining Company's Misterfeldt No. 1 well, a dry hole 4 miles south of the producing area, also off the anticline, it is 438 feet thick.

If the gas rock is Clayton limestone, it was deposited as a blanket after the erosion period at the end of the Cretaceous period.

Faulting has been suggested by many geologists to explain the irregular structure. The principal argument in favor of faulting is the fairly constant thickness of the Porters Creek clay, but with the gentle slopes of the erosion surface at the top of the chalk—the steepest found so far is less than 10°—and the quiet waters which undoubtedly prevailed during deposition of the mud (Porters Creek clay), the clay would be a blanket deposit with very small differences in thickness on the high and low spots of the old sea bottom. Further drilling to the base of the chalk should determine if the contour of the base coincides with that of the top, thus proving or disproving the theory of faulting.

No accurate structure map can be drawn on the base of the Selma because so few wells have been drilled to that depth. Only three wells have assuredly entered the Carboniferous, and in only one of these have sufficient cores been taken to reveal structural features of these rocks. All the cores showing bedding in the Carboniferous in the Gulf Refining Company's Hamilton No. 1 well[1] indicate dips ranging from 20° to 30°. As officials of the Gulf Refining Company are certain that the Hamilton hole is vertical these rocks must have been considerably deformed.

Gas development.—On June 15, 1932, 90 gas wells had been completed with a total daily open-flow capacity of more than 2,800 million cubic feet. Only 35 dry holes had been drilled, and 10 wells were being drilled or were shut down. The gas has a high calorific value, averaging 940 British thermal units. The gas is used for domestic and commercial heating and is distributed by the United Gas Public Service Company and its subsidiaries, and the Public Service Corporation of Mississippi. Edge water has been reached in many wells on the outer limits of the field. The possible productive area probably is limited to less than 7,000 acres within a radius of 4 miles from the center of Sec. 2, T. 5 N., R. 1 E.

[1] See Table II for location of wells mentioned in the text.

PRE-TERTIARY ROCKS

CRETACEOUS

Selma chalk.—The Selma chalk, ranging from 340 to 440 feet thick, consists of white porous chalk in soft powdery form or very slightly consolidated, and of hard limestone cut by veins of calcite. Paleontologists have found a few Cretaceous foraminifers, ostracods, a Mesozoic coral, fragments of gastropods and echinoids, and calcareous algae. The Selma chalk at Jackson may include the offshore equivalent of the Eutaw formation, which has not been recognized in the field, although no fossils that prove this have been found. The upper part of the chalk, as found in wells drilled on the sides of the anticline, is probably not represented in wells on top, due to removal by erosion.

Tuscaloosa formation.—Underlying the Selma are beds of clay, sand, and conglomerate referred to the Tuscaloosa formation. The thickness of the Tuscaloosa in the Jackson area varies, but probably exceeds 400 feet. Near the base of these beds are found various kinds of igneous rock and tuffaceous material.

In most of the wells from which cores have been examined, the Tuscaloosa consists of red and white sand, clay, and conglomerate. In two wells, however, the beds immediately underlying the chalk consist of gray, brown, and black carbonaceous, micaceous shale, with some pyrite. These rocks are also probably Tuscaloosa in age, although they do not resemble the Tuscaloosa in the other wells.

C. S. Ross examined cores of conglomerate and sandstone from depths of 3,309–3,342 feet in the Gulf Refining Company's Hamilton No. 1 well and describes them as follows.

> The red pebbles of the conglomerate are composed of iron oxide and calcite possibly derived from the alteration of ferruginous carbonate. The groundmass is composed of angular quartz grains embedded in calcite.

Underlying this conglomerate is a sandstone very little changed by proximity to an igneous rock made up of fine-grained angular quartz, clay material, and much mica. There are bodies of igneous rock both above and below the depth at which this core was taken although none are in contact with it.

The only fossils so far found, excepting obscure, comminuted plant remains, are from depths ranging from 3,842 to 3,846 feet in the Lion Oil Refining Company's Misterfeldt No. 1 well. Stephenson[1] examined the core and makes the following statement.

[1] L. W. Stephenson, Letter to C. L. Moody, October 18, 1929.

The sample of calcareous chalk contains numerous molds and prints of fossil shells, mostly fragmentary, among which were identified *Pecten* sp. (smooth), *Cardium* sp. (small), and *Veniella* (*Etea*)? The fossils are not sufficiently diagnostic to determine the stratigraphic position of the containing bed. There is no evidence to preclude the possibility of its representing a marine facies of the Tuscaloosa formation.

In this connection it is interesting to note that fragments of megascopic fossils were found in 1928 in the Tuscaloosa at a depth of 3,196 feet in the Lauderdale Oil and Gas Company's Gunn No. 1 well, Lauderdale County, Mississippi, by C. D. Fletcher, at that time district paleontologist of the Gulf Refining Company. Stephenson[1] reports having seen poorly preserved prints of *Ostrea* and *Modiolus* in clay of Tuscaloosa age, in an outcrop about 4 miles east by north of Maplesville, Chilton County, Alabama. This indicates at least brackish-water conditions of sedimentation at this locality at the time the clay was deposited.

The Louisiana Gas and Fuel Company's Harris No. 1 well passed through 250 feet of alternating beds of shale, sand, and volcanic agglomerate, from depths of 2,975 to 3,227 feet. C. S. Ross studied a core of volcanic agglomerate from a depth of 3,197 feet. The sample contains coarsely crystalline, sharply angular fragments of calcite, many of which contain apatite. There are also phenocrysts of fine-grained biotite, apatite, orthoclase, and melanite garnet in a very fine groundmass, some of which is vesicular. There is a very great variation in the texture of igneous rock in the same thin section. The material in this core evidently was not transported far, in fact it may have been blasted out of a volcano. The apatite in the calcite crystals suggests contact with an igneous rock.

Igneous rocks.—In the Hamilton well three masses of igneous rock near the contact of the Tuscaloosa and the Carboniferous were described by Ross as having almost the composition of andesite or diabase although the minerals are now completely altered. Two of these bodies were in the Tuscaloosa and one in the Carboniferous. At the bottom of this well from depths of 4,017 to 4,027 feet hard, almost impenetrable, black igneous rock was cored. Ross describes this as nepheline syenite and states: "The sodic character and the minerals that have developed suggest that it is related to similar rocks of Arkansas."

The Gulf Refining Company's Rainey No. A-1 well entered

[1] Oral communication.

igneous rock at 2,996 feet and was still in it at the bottom of the hole at 3,607 feet. This rock is described by Ross as lamprophyre. It is all essentially similar, but the upper part is slightly different in texture, resembling peridotite.

Time of igneous activity.—Near the bottom of the Misterfeldt well at a depth of 3,940–3,948 feet a core was taken that definitely establishes the relative age of the overlying material. The top of this core is very calcareous sandstone composed of angular grains of quartz, large biotite crystals and orthoclase, loosely cemented by green chloritic material. The bottom of the core is composed of hard, calcareous, glauconitic sandstone with fragments of microcline crystals and green and black igneous rock, probably derived from a fine-grained volcanic rock. The volcanic material in the sandstone shows definitely that the sandstone was deposited subsequent to volcanic activity at Jackson. The Misterfeldt well was drilled to a total depth of 4,075 feet and abandoned in the Tuscaloosa formation in soft, white, water-bearing sand. Cores from the Hamilton well taken below the base of the chalk have been compared with, and found to be similar to, those from the same relative stratigraphic position in the Misterfeldt well. In a series of beds composed of red and white sand, clay, and conglomerate such as is present in the two wells, lithologic resemblance may not, of course, necessarily indicate age equivalence. But if the correlations, as stated, are correct, some of the beds above the contact of the Tuscaloosa and the Carboniferous in the Hamilton well are obviously younger than the body of igneous rock which furnished the fragments found at a depth of 3,940–3,948 feet in the Misterfeldt. It has been suggested that the pre-Selma rocks in the Misterfeldt well may not be present in the Hamilton well, because they were eroded away before the Selma chalk was deposited, that the former may be Tuscaloosa and the latter Trinity. There is no evidence so far either to confirm or deny this opinion, but the writer believes that in both wells the rocks are Tuscaloosa.

If the contact of the Tuscaloosa formation and the Carboniferous has been placed correctly, the igneous activity must have taken place in Tuscaloosa time, for igneous rocks in the Hamilton well cut basal Tuscaloosa beds, and in the Misterfeldt well eroded fragments have been found in the Tuscaloosa. The intrusion must, therefore, have taken place early in Tuscaloosa time.

The nepheline syenite cored in the Hamilton well is an exceptional type, and as stated by Ross, probably is related to igneous rocks near

Hot Springs, Arkansas. H. D. Miser[1] states that the exposed igneous rocks in Arkansas were probably all derived from one magma and that their intrusion thus occurred at almost the same time. In discussing the age of the diamond-bearing peridotites near Murfreesboro, Arkansas, he makes the following statement.[2]

The peridotite is younger than the Trinity formation, of Lower Cretaceous age, and is not younger than the Tokio formation, of Upper Cretaceous age. The volcanic activity that produced the peridotite probably accompanied the down-warping of the Mississippi embayment early in the Upper Cretaceous epoch.

It is probable that the igneous activity at Jackson took place at approximately the same time as that in Arkansas. If so, this may prove to be a basis for correlating the Tuscaloosa formation with beds of corresponding age in Arkansas. Assuming that the igneous rocks in the two areas are of the same age, the lower part of the Tuscaloosa that is cut by igneous rocks and in which fragments of igneous rock have been found, must be younger than the Trinity and not younger than the Tokio of the Arkansas section; this suggests that the lower part of the Tuscaloosa corresponds in age with part of the Woodbine formation, which underlies the Tokio, but which is not present at the peridotite locality in Arkansas. The Tuscaloosa has been correlated with the Woodbine,[3] and this correlation substantially agrees with the data given in this paper.

CARBONIFEROUS

In 1930, Charles Butts and H. D. Miser examined cores from the Hamilton well and suspected that they represented rocks of Carboniferous age. Subsequent comparison of several cores from this well with hand specimens from the outcrop of the Pottsville formation in Alabama and the discovery of fossil plant material in a few cores have confirmed this. Ross reports as follows about the core from 3,492 to 3,511 feet.

This is a banded sandstone. The grains are angular and predominantly quartz, but feldspar and mica are also present. The banding is partly due to zones that are richer in calcite, and part of this calcite appears to be second-

[1] "Hot Springs, Arkansas," *U. S. Geol. Survey Geol. Atlas U. S., Folio 215* (1923), pp. 7–8.

[2] H. D. Miser and A. H. Purdue, "Geology of the DeQueen and Caddo Gap Quadrangles, Arkansas," *U. S. Geol. Survey Bull. 808* (1929), p. 115.

[3] O. B. Hopkins, "Structure of the Vicksburg-Jackson Area, Mississippi," *U. S. Geol. Survey Bull. 641-D* (1916), p. 115.

ary. The specimen contains some disseminated pyrite, and some that is concentrated in veins of secondary calcite. There is, therefore, evidence of mineralization of the sandstone by the igneous rock.

The bands dip at an angle of 20°, and if this banding is not due to cross-bedding these older rocks have been considerably deformed.

The contact of the Tuscaloosa and Carboniferous in the Hamilton well has been placed at 3,418 feet. The rocks immediately above this point are fine white sand and red sandy clay, and resemble closely the other rocks in the Tuscaloosa section. The cores taken from 3,418 feet to 3,433 feet are cut by numerous shear zones along which iron oxide and calcite have been introduced. This sandstone is decidedly different from any rock above it and probably represents the top layer of the series of Carboniferous rocks.

The cores from 3,433 feet down to 3,718 feet in the Hamilton well are predominantly compact gray sandstones, mostly calcareous, many with dips ranging from 20° to 30°. Interbedded with these are hard red and gray sandy shales. A core from 3,718 to 3,720 feet is conglomerate composed of gray calcareous pebbles in a white calcareous matrix. Similar material was later found in cores from the Louisiana Gas and Fuel Company's Harris No. 1 well and the Gulf Refining Company's Hanna No. 1 well.

A core from a depth of 3,891 to 3,910 feet in the Hamilton well, containing carbonized wood, was submitted to David White, who states that although the material is not specifically determinable, he is confident that it is Paleozoic, probably of Pottsville age.

Another core from an unknown depth, but plainly from the Carboniferous section in this well, contains some carbonized wood that was examined by Taisia Stadnichenko and Charles B. Read. Read states that the pitting of the fibers of this wood is of a type that is common in Carboniferous woods, but very rare in those of the Cretaceous. Miss Stadnichenko states that the degree of carbonization suggests high rank bituminous coal. Coal of this class is more common in the Paleozoic than in younger deposits and so far as known has not been found in coastal plain deposits. The possibility is recognized, however, that the near-by volcanic activity at Jackson in Tuscaloosa time might have caused the metamorphism of wood fragments into coal.

In the Harris well a core taken at a depth of 3,227–3,232 feet consists of hard calcareous sandstone with pellets of black shale. This core resembles the core from the Hamilton well taken at a depth of 3,718–

3,720 feet, and possibly represents approximately the same horizon. Butts says that material of this type is very common on the outcrop of the Pottsville formation.

Similar material was found in the Gulf Refining Company's Hanna No. 1 well, at a depth of 3,167–3,169 feet. Two cores from this well taken below the one called Carboniferous consist of very hard red and green sandstones. These have been called Trinity by many geologists, but according to Butts red sand and clay are not at all uncommon on the outcrop of the Pottsville formation in Alabama.

REGIONAL RELATIONS

The discovery of steeply dipping Carboniferous rocks at Jackson suggests that the belt of Appalachian folds may extend westward from Alabama through Mississippi. Future deep drilling between Jackson and the outcrop of Paleozoic rocks in Alabama may give other points to complete the picture of this ancient chain of mountains.

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MICROFLORA OF OIL WATERS AND OIL-BEARING FORMATIONS AND BIOCHEMICAL PROCESSES CAUSED BY IT[1]

T. L. GINSBURG-KARAGITSCHEVA[2]
Moscow, Union of Soviet Socialist Republics

ABSTRACT

The examination and analysis of more than 100 samples collected from oil wells and sources of sulphurous springs in various oil regions (Apsheron, Saliany, Grozny, Naphtalan) showed the presence of certain groups of micro organisms, characteristic for pools charged with hydrosulphurous fermentation. This microflora of oil waters and oil-bearing formations is found experimentally to produce combustible gases. The results of the experiments suggest that these biochemical processes observed under laboratory conditions are the same processes active on a vast scale in the origin of natural gas and petroleum.

In 1924 at the suggestion of N. G. Ushinsky, director of the Microbiological Laboratory at the Azerbaijan State University in Baku,[3] the writer began her research on microbiology of the sulphurous springs of Sourakhany (near Baku on the Apsheron Peninsula) which are used for medical purposes. As it was for the first time that these investigations were attempted, it was impossible to predict their results.

In addition to natural exits in the form of small sulphurous springs in various parts of the oil fields of Apsheron, hydrosulphuric waters in Sourakhany accumulate into some artesian wells with the capacity varying from 7,000 to 8,000 gallons per day. Traces of oil are commonly found in some of these wells. The oil is steadily increasing in quantity, so that some of the sulphurous springs which formerly gave perfectly clean water now emit water with a considerable percentage of oil. This change occurred during the time of the writer's study, that is, in 6 years.

This microbiological investigation disclosed that every sample (taken under due precautions to preserve sterility) from closed wells

[1] Manuscript received, April 25, 1932. A brief summary of this study is given in the Archives of the Second International Congress of Soil Science.

[2] State Research Institute of Petroleum. Introduced by R. D. Reed.

[3] This investigation begun at the Azerbaijan State University, was continued at the Azerbaijan Research Institute of Petroleum at Baku and is now carried on at the State Research Institute of Petroleum at Moscow.

and sulphurous springs, contained groups of micro-organisms, characteristic for pools with hydrosulphide fermentation (seas, firths, mud lakes).

All the samples, in A. van Delden's medium, disclosed the presence of a microspira which was a powerful reducer of sulphates with the formation of H_2S and FeS. Bacteria and actinomycetes secreting H_2S, NH_3, and other products, on albumen and sulphurous media, on peptone beef broth and agar, were isolated (among those a small, spore-lacking thin anaerobic rod which liquefied agar-agar); denitrificators have also been isolated.

Such results obtained through examination and analysis of a series of samples (the waters of some springs and wells were analyzed 2 or 3 times at wide intervals) gave enough reason to suppose that the hydrogen sulphide of the sulphurous-salty waters of Apsheron appeared as an effect of biochemical processes caused by live organisms.

To support this supposition are the following facts: samples of loamy species taken from oil wells during drilling at various depths (maximum, 900 meters) with the addition of water-pump drinking water after standing in a thermostat in hermetically sealed jars filled to the top, gradually blackened (formation of FeS); H_2S appeared in the jars and at the examination of the centers of black color a microspira was always found. It follows then that in the depths of the so-called "productive"[1] layers of Apsheron, all conditions are present necessary for hydrosulphurous fermentation.

These interesting data, obtained by the writer, gave rise to a new series of problems for the solution of which further prolonged research became necessary.

The vast quantity of hydrosulphurous waters in the oil regions, the presence of oil in many of these waters, in many places, besides the presence of hydrosulphide in waters obtained together with the oil from producing layers,—all this suggested a possible genetic relation between the salty and sulphurous springs freely escaping to the surface, and the oil waters from the oil wells. Therefore the writer decided to extend her investigations also to the latter. With this purpose, she filled (under all possible aseptic precautions) several sterilized bottles with water mixed with oil from the wells of various regions of oil production, first on the Apsheron Peninsula (Bibi-Aybat,

[1] As it is known, the origin of the so-called "productive" layers of Apsheron dates from the Pliocene period (the Tertiary system, Neogen); they consist of loams and sands the various layers of which at a different depth contain sulphurous-salty waters, oil, and gases.

Sourakhany, Shoubany, Balakhany, Pouta, Kala), then in the Saliany region near the mouth of Koura River (Baba Zanan), at Grozny, in the northern Caucasus, and finally in Naftalan, where the oil is known for its marvelous healing powers. Three more samples were taken from some small gas-ejecting craters near Pouta on the Apsheron.

Altogether more than 100 samples have been examined. They were taken from oil-bearing formations of various depths down to 1,000 meters.[1] These samples generally consisted of water, some with an admixture of oil-bearing formations over which a small or a large layer of oil was found.

The saltiness of the waters from different wells varied from 1 to 17°B. The temperature of the samples ranged from 17° to 45°C. One of the peculiarities of these, as generally of all oil waters was a small percentage of sulphates, in some a complete absence of sulphates.[2]

All samples at first were examined mainly to detect the following biochemical processes: (1) the reduction of sulphates in van Delden's medium with the formation of H_2S and FeS; (2) the formation of H_2S on an albumen medium (peptone-beef agar and broth); and (3) the process of denitrification (Giltay's medium was used). Three per cent of sodium chloride was added to all media.

All the examined samples of oil containing waters taken from oil-bearing formations showed a positive reaction to the previously mentioned processes. In all of these samples a microspira was discovered, reducing sulphates at a temperature below 45°C. The formation of H_2S and FeS required nearly a week for some samples; for others, 2 or 3 days after insemination. The maximum quantity of H_2S in a liquid sulphate medium was 0.5 gr. per liter.

A group of microbes also was extracted, which, under anaerobic conditions in addition to H_2S and FeS, formed mercaptans on van Delden's medium with the addition of peptone.

In a peptone-beef medium, vigorous destroyers of albumen and sulphurous matter, facultative or strictly anaerobic bacteria, were isolated. In Giltay's medium a large quantity of bubbles of gas, foam,

[1] Samples were taken from the bottom of oil wells by means of a sucker or directly from an oil spring.

[2] Some geologists explain the absence of sulphates in oil waters by the reducing powers of the oil itself. By a series of experiments (Bastin), however, it has been proved that in the ordinary mild temperature of oil deposits, through the influence of hydrocarbons, the reduction of sulphates does not occur.

and the appearance of nitrous acid, showed the rapid process of denitrification. Nitrous acid appeared in some samples 24 hours after insemination, and a week later the process of decomposition of nitrates was accomplished. In this way the investigations gave sufficient proof of the identity (according to their respective biochemical processes) of the microflora of the waters of sulphurous springs with that of the oil-well waters. The presence, in all the samples of oil waters, of microspira, made it possible to explain the diminution or complete absence of sulphates in them, as a result of biological changes caused by micro-organisms living in the depths of oil fields.

The writer's first study, dealing with the results obtained after a 2-year period of research, was published in the summer of 1926. In March of the same year a short statement was published in the United States, and in December appeared an article by E. S. Bastin on the microbiological study of the oil-well waters of North America. Bastin examined samples of oil waters, stated the process of the reduction of sulphates, and found a microspira in many of his samples. Thus independently and nearly at the same time in the Union of Soviet Socialist Republics and in the United States discovery was made of the presence in oil-bearing formations, of micro-organisms which under laboratory conditions caused biochemical processes characteristic of pools charged with hydrosulphuric fermentation.[1]

This fact, as already stated, made it possible to give a natural explanation of the small quantity of sulphates found in oil-well waters, which is one of the many mysterious phases of the formation and presence of oil in nature.

Nevertheless, many geologists considered this discovery in a very skeptical manner. They suspected the possibility of foreign matter having soiled samples when they were being taken, or having affected the wells during drilling and production, or the possibility of surface waters having entered the wells. These conjectures were reasonable and led to the necessity of making further investigations of such a kind as would either reject or prove the truth of these suppositions.

With this aim the following research was organized.

1. Pipe water taken from a pit (the so-called "ambara," water with a loamy solution, which is pumped into oil wells during the drilling process) in the Kala region; also three samples of Grozny pipe

[1] Professor N. G. Ushinsky, basing his statement on the data gathered, offered the supposition that the processes going on at the bottom of oceans and seas and in the depths of oil fields are identical, their origin being due to the activities of micro-organisms.

water were examined to determine the possible presence of the process of reduction of sulphates.

No H_2S or FeS, however, was formed in the liquid van Delden's medium after preparation of the culture with this loamy water. Neither was any microspira discovered.[1] Therefore any doubts as to the possibility of foreign matter entering with the water used for washing during drilling, in this case, were decidedly removed.

2. At the same time a comparative examination of the microspira was commenced in pure and mixed cultures taken from oil-bearing formations of different regions in order to state the concentration of sodium chloride in van Delden's medium, necessary to the development and maximum production of hydrosulphide of the microspira. It is known that oil-well water, even of one field, has a different degree of saltiness in various wells. The writer had samples of water with a degree of saltiness varying from 2° to 17°B.

Eight series of such experiments were made. The amount of sodium chloride used for each sample varied from zero to 18 per cent. The cultures were kept in a thermostat at 25°–35°C.

The presence of $NaCl$ varying from 2 to 7 per cent (all other conditions being equal), the maximum of H_2S in different samples varied. A strict dependency was stated between the optimum quantity of $NaCl$ in a medium and the saltiness of a sample. The greater the saltiness of the tested sample, the higher was the percentage of $NaCl$ at the maximum point of the formation of H_2S. For example, the water from well No. 6 (1,007 meters deep) in Kala, Apsheron, having 17°B of saltiness, the maximum of H_2S was obtained with 7 per cent of $NaCl$. Up to this time, two kinds of microspira[2] (in river and sea waters) have been described: that of fresh water (*Microspira desulfuricans*) developing under 0–2 per cent of $NaCl$ and that of the marine water (*M. aestuarii*) developing under 1–6 per cent and giving a maximum of H_2S under 3 per cent of $NaCl$. Therefore, the microspira from the oil deposits obtained by us must be acknowledged as a new variety; this microspira accommodating itself to vast fluctuations of the concentration of $NaCl$, in our experiments, shows the ability to reduce sulphates with the presence of $NaCl$ ranging from 1 to 18 per cent.

In this way, in our opinion, the supposition that any described

[1] Bastin obtained the same negative results while examining surface waters.

[2] The writer does not know the optimum of $NaCl$ for the third species of microspira *Vibrio thermodesulfuricans* (Elion).

variety of microspira of fresh and marine waters may have entered the wells from outside fails. The optimum of $NaCl$ for the microspira of each sample, depending entirely on the degree of saltiness of the water from that oil-bearing formation, with full certainty, as it seems to the writer, points out the fact that we have a species which has adapted itself to the concentration of salts in that particular oil field.

The next problem was to obtain fermentation with the formation of combustive gases during the decomposition of various matter of animal and plant origin.[1] The writer was guided by the following ideas. If the obtained microflora be of an oil-well origin, and if it be admitted that in the hermetically sealed oil bed in former geological epochs, and possibly to-day, biochemical processes have been producing, and are continuing to produce, the usually found oil, gases, sulphurous-salty waters, et cetera, then the micro-organisms of the examined layers should furnish the same products under laboratory conditions and on a suitable medium.

As has already been stated, insemination of cultures of these oil-well waters causes a well defined process of the reduction of sulphates, the formation of H_2S on an albumen medium, and the dissolution of nitrate up to pure nitrogen; also it was necessary to determine if these oil microbes were able to form hydrocarbons.

It is known that the most studied microbiological processes are those of the methane fermentation of cellulose and albumens. Guided by the studies of V. L. Omeliansky (see Bibliography, Nos. 10–13), it was decided to organize the necessary experiments.

The culture which developed on liquid van Delden's medium after insemination of oil water from oil wells of Bibi Aybat (Apsheron) was transferred, with aid of a sterilized pipette, into two long-necked flasks filled with a solution of mineral salts prepared after Omeliansky.[2] Into one of these flasks, some chalk and filter-paper, cut into thin strips, were added (this formed the cellulose); into the other,

[1] The writer became acquainted with the work of E. McKenzie Taylor concerning methane fermentation only after having made her experiments of the methane and hydrogen fermentation of albumens, cellulose, and fatty acids.

[2] The Omeliansky's solution used has the following composition:

Ammonium phosphate	1 gm.
Dicalcium phosphate	1 gm.
Magnesium sulphate	0.5 gm.
Calcium chloride	0.1 gm.
Sodium chloride	30 gms.
$FeCl_3$	Traces
Distilled water	1 liter

1 per cent of peptone and pieces of hard-boiled egg-whites were introduced. Both flasks were put into a thermostat and kept at a temperature of 45°C. After several months, there was no change whatever in the flask with the cellulose. In the other, the medium had become somewhat turbid, and bubbles of gas appeared a few days later. The fermentation went on abundantly evolving nearly 150 cubic centimeters of gas per day. The pieces of egg-white were rapidly diminishing, taking the form of transparent yellowish lamina partly covered with a black coating. A somewhat unpleasant, strong odor, characteristic of the decomposition of albuminous sulphurous matter, emanated from the flask. The fermentation in the flask having ceased, H_2S, NH_3, CO_2, and mercaptans were obtained in the liquid. At the beginning of fermentation the presence of gases was as follows: CH_4 up to 70 per cent; CO_2 from 2 to 25 per cent, an insignificant amount of H, and in some samples 0.3 to 1.8 per cent of unsaturated hydrocarbons (consumption by a strong solution of sulphuric acid). Later the quantity of hydrogen increased. At last when a pure culture was extracted from the flasks by means of a rod with a spore at its end, a pure hydrogen fermentation set in. The quantity of hydrogen in the gases amounted to 80 per cent. It follows, therefore, that the obtained bacillus belonged not to a methane but to a hydrogen fermentation of albumens. Thus, during the fermentation of albumens the same phenomenon had occurred as that described by Omeliansky during the fermentation of cellulose; therefore, in a mixed culture agents of both methane and hydrogen fermentation are found, the latter being more hardy than the former. It is interesting to note that Omeliansky also was first able to extract the agent of hydrogen fermentation of cellulose and, at a further period of his research, that of the methane fermentation. The bacillus of hydrogen fermentation of albumen obtained by the writer is also a powerful agent of hydrosulphuric fermentation; formation of H_2S and FeS, however, occurs on van Delden's medium only after the addition of 1 per cent peptone. If no peptone is present, then in this medium no reduction of sulphates occurs. In a pure culture the bacillus causes a vigorous fermentation of albumens which, however, ends very soon, while in a mixed culture, the fermentation continues for a long time with equal intensity until nearly complete dissolution of the pieces of egg-white.

The experiments demonstrated the presence of agents of methane and hydrogen fermentation of albumens in oil waters of Apsheron, showing at the same time the absence of agents of fermentation of

cellulose. This made way for two suppositions: either the examined oil fields contained no cellulose fermentation agents, or there could be some of them inhabiting only the earth strata without getting into the waters. This led to another task,—to examine not only the oil and water but also the formations at the bottom of the producing oil wells. According to some geologists oil accumulates not in the early formations where it originated, but in sands (the problem of the so-called "migration of oil"); however, A. D. Archangelsky states that according to his research the oil of the Grozny fields, North Caucasus, must be considered as being of primary formation, that is, as having originated in the same formations which contain it now. Therefore a study of the Grozny oil-field formations seemed to be of a particular interest. Carefully following instructions given in order to avoid contamination, fifteen samples were taken into sterilized liter jars with ground-in stoppers. The samples consisted of a layer of sand and dark clay a few centimeters thick, of water, and of a thick layer of dense and heavy oil. When put into a thermostat, large bubbles of gas escaped from the layer at the bottom of the jar, and later, the entire surface was covered with small, conical protuberances. After the insemination of the water together with the sand and clay, all the samples excepting one with light-colored sand and surface water gave a positive result as to reduction of sulphates and denitrification. On beef-peptone mediums H_2S and NH_3 were formed, so that in this respect, they in no way differed from the previously examined samples from the Apsheron and other oil fields; the microspira was found in all the samples with the exception of the sample mentioned as containing light-colored sand.

Methane and hydrogen fermentation of albumen also was found; although 2 months after being sown, an anaerobic fermentation of cellulose also began, going on vigorously so that the pieces of filter-paper were gradually dissolved, and nearly 5 months after insemination only a small sediment consisting of small flakes remained at the bottom of the flask.

The gases determined were CH_4, CO_2, N, O_2; no hydrogen was present.

Most of the culture from the sediment at the bottom of the flask consisted of very mobile curved thin and long rods, some with a small spore at the end. Thus in the water and strata of the bottom of the oil wells of Grozny, an agent of methane fermentation of cellulose was discovered. Inseminations were made from the flask containing

fermenting cellulose into three flasks filled with a mineral solution of the same consistence, but with the following additions: flask A: 1 per cent gum arabic, 1 per cent chalk and 0.1 per cent asparagin; flask B: 1 per cent potassium acetate, 0.5 per cent asparagin; flask C: 1 per cent potassium lactic. Flasks A and B developed vigorous fermentation with abundant formation of gas.

The analysis (made, 18. IX. 1928) of gases from flask A shows the following data: CO_2, 2.4 per cent; O_2, 3.7 per cent; N, 46.8 per cent; no H; hydrocarbons, 47.1 per cent.

In flask C a strong fermentation set in only after a third resemination.

Omeliansky (Bibliography, No. 12) who studied biological processes with the formation of combustible gases, points out, as is known, besides fermentation of cellulose and albumen another important natural source of these gases: their formation during the fermentation of interjacent products of the decomposition of albumen and vegetable matter, which are acetate, butyric, and lactic acids and also furfuroids (in his experiments: gum-arabic).

In three samples of water and sand from the Grozny oil wells the writer has found agents (at present the work of isolating them in a pure culture is being carried on) of all the kinds of fermentation described by Omeliansky (except butyric acid fermentation, because of the lack of the necessary reagents) and she has obtained a pure methane fermentation (gum, acetate, lactic acid, and cellulose); in one case, a pure hydrogen fermentation of albumen and in the other, a methane fermentation of albumen.

Thus the attempt to get combustible gases as a result of the activities of oil bacteria succeeded. We have to consider the following facts: (1) the vast quantity of combustible gases in the oil-field regions and the lack of any plausible explanations of the origin of these gases; (2) the presence in oil-bearing formations of microbes which under laboratory conditions cause fermentation with the formation of combustible gases, of animal and vegetable matter, and of interjacent products of the decomposition of either; (3) finally, we have to take into account those immense quantities of organic matter which, according to Vernadsky, are present in the so-called biosphere. Thus it becomes impossible not to have suppositions as to the possibility of the formation of these combustible gases in the depths of oil fields as a result of the activities of certain live organisms. As to the origin of other hydrocarbons besides methane, the problem is not yet

solved by us because a series of technical difficulties prevented a complete analysis of the liquid and gas products of decomposition during fermentation.

It must be noted that during combustion, the gas often produced a yellow flame, which could serve as evidence for the presence of heavy hydrocarbons; also, many analyses of gases showed the presence of unsaturated hydrocarbons.

SUMMARY

1. The examination and analysis of more than 100 samples collected from oil wells and sources of sulphurous springs in various oil regions (Apsheron, Saliany, Grozny, Naphtalan) showed the presence of certain groups of micro-organisms, characteristic for pools charged with the hydrosulphurous fermentation.

2. The following biochemical processes proved to be identical for microflora of all the samples.

a. The reduction of sulphates under anaerobic conditions with the formation of H_2S and FeS. In all the samples, a microspira was found.

b. The formation, in addition to H_2S and FeS, of mercaptans on the sulphate van Delden's medium with 1 per cent peptone. A pure culture of micro-organisms possessing these qualities has been isolated.

c. The formation of H_2S and NH_3 on an albumen and sulphurous medium (broth and agar).

d. The process of denitrification with the decomposition of nitrates into nitrous acid and free nitrogen.

e. Anaerobic methane and hydrogen fermentation of albumens with the formation of the following products of decomposition: CH_4, H, CO_2, N, H_2S, NH_3, and mercaptans.

In a pure culture, the bacilli of hydrogen (Apsheron) and methane (Grozny) fermentation of albumen have been isolated.

3. Through analysis of samples of microflora of oil formations and waters from the oil wells of Grozny, the following biochemical processes, besides the afore-mentioned, have been determined: anaerobic methane fermentation of (1) cellulose, (2) furfuroids, (3) lactic acid, and (4) acetic acid.

Without presenting any final statement as to the causative agents of these processes, for the work of isolating them is not yet accomplished, it is assumed on the basis of the many observations made

by the writer, that these are strictly anaerobic rods each with a spore at its end (named by Omeliansky the "drumsticks"). These bacteria vary in length and thickness so that they evidently should be classed with that group of bacilli with end spores which were discovered by Omeliansky during his study of the same biochemical processes[1] (Table I).

4. Under slight admittance of oxygen (the insemination being made by injection into agar and gelatine media) these rods form cocci-shaped bodies. Being in the stage of "cocci," the bacillus loses its ability to cause fermentation (a special study, which has already been commenced, will deal with the problem of polymorphism of these rods).

5. During investigation of the optimum of sodium chloride for microspira of various oil wells a full dependency has been determined between the saltiness of a sample and the quantity of $NaCl$ with which the maximum of H_2S can be extracted.

In the writer's experiments the microspira developed at 1–18 per cent $NaCl$. The maximum of H_2S for the microflora of samples of various saltiness was at 1–7 per cent $NaCl$.

6. In fresh surface waters, used for washing out oil wells, no microspira was found.

A study of the data suggests that the biochemical processes observed under laboratory conditions are only the reflections of the processes which are active on a gigantic scale in the depths of oil fields.

A series of facts observed in oil regions, which in spite of long and laborious study have not been explained, can be understood if regarded as a result of a series of biochemical processes. Such are the small quantity of sulphates found in oil waters, the presence of sulphurous and nitrous compounds in oil (Gourvitch), particularly the presence of hydrosulphide and mercaptans as well as the vast quantities of gaseous products in these regions. We have obtained all these products by charging the respective mediums with micro-organisms from oil wells. As to the problem of the origin of oil itself, from this viewpoint, not wishing to mention any suppositions before getting final results from the experiments, the writer takes the liberty to quote the following words of a well-known Russian scientist, V. I. Vernadsky (Bibliography No. 18, p. 321, note 505).

[1] The optimum quantity (3 per cent) of $NaCl$ in the medium shows that oil bacilli are really new varieties of the same group; the bacilli of Omeliansky required only traces of $NaCl$.

TABLE I

COMPOSITION OF GASES IN VARIOUS PROCESSES OF FERMENTATION

(Shown in Percentage)

			CO_2	O_2	H_2	CH_4	N	C_mH_n	*Remarks*
1	Fermentation of *albumens* charged with mixed culture taken from oil-well waters of Bibi-Aybad (Apsheron)	a	25.6	5.7	Undetermined	45.9	22.8		Gas often burns with yellow flame
		b	2.4	5.2	Undetermined	73.1	19.3		
		c	14.6	5.42	0.34	58.46	21.14		
		d	50	4.6	15.4	1	29		
2	Hydrogen fermentation of *albumens* charged with pure culture of "drumsticks" taken from afore-mentioned mixed culture	a	15.98	0.61	81.08	—	2.23		
		b	40.18	2.13	49.51	—	8.18		
		c	15.88	1.01	79.25	—	3.86		
		d	39.92	1.15	61.47	—	4.46		
		e	1.6	3.2	56	—	39		
		f	18.8	4.4	28.9	—	48.6		
3	Methane fermentation of *cellulose*. Mixed culture from Grozny oil waters and strata	a	1.5	0.5	—	56.2	41.8		Gas often burns with phosphorescent flame
		b	21.6	0.77	—	74.5	3.13		
		c	8.75	3.81	—	72.29	15.15		
		d	7.1	—	—	80.7	11.3	0.9	
		e	1.9	1.9	—	67.0	23	62.0	
4	Methane fermentation of *gum-arabic*. Same culture as in No. 3	a	2.4	5.7	—	47.1	46.8		
		b	29	0.2	—	32.5	38.3		
		c	0.84	1.48	—	66.21	31.47		
		d	14.8	1.2	—	78.7	4.5	0.8	
		e	2.4	1.57	—	89.75	6.28		
5	Methane fermentation of *lactic acid*. Same culture as in No. 3 and No. 4	a	0.42	2.25	—	59.8	37.53		
		b	3.6	—	—	61.8	34.6		

The discovery of bacteria in the depths of oil wells makes us change our beliefs as to the genesis of oil. Perhaps anaerobic life causes the formation of oils, and we then have a process going on, on fundamental lines all the time within the limits of the biosphere.

The plan of our laboratory includes investigations which will perhaps help solve this important and complicated problem, which has brought forth widely differing hypotheses of many prominent scientists.

At present, besides the afore-mentioned work, an extensive series of comparative examinations of samples of formations from wells now being drilled, is being initiated. The purpose of this is to trace the connection between different geological layers and horizons and their respective microflora causing under laboratory conditions certain biochemical processes.

If it is found possible to ascertain such a connection, petroleum geology will perhaps obtain, in the guise of these characteristic groups of micro-organisms, one of the most trustworthy signs of oil location.

The writer hopes that further microbiological examination of oil waters and formations by coöperation of chemists and geologists will finally determine the already suggested connection between pools charged with hydrosulphurous fermentation, and the processes of the formation of oil; this also may help to solve the problem of the biochemical circulation of matter in closed pools, not only now but in previous geological epochs.

BIBLIOGRAPHY

1. Ambrose, *Underground Conditions of Oil Occurrences* (1923).

2. A. D. Archangelsky, "Of the Ancient Origin of Sulphurated Hydrogen Fermentation in the Sea Pools of Crimea and Caucasus and the Probable Connection of These Phenomena with the Formation of Oil," *Neftjanoe Chozjaistvo*, No. 4 (1926).

3. ——— ———, *Conditions of the Formation of Oil in Northern Caucasus* (1927).

4. Edson S. Bastin, "The Problem of the Natural Reduction of Sulphates," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 10, No. 12 (December, 1926), pp. 1270–99.

5. T. L. Ginsburg-Karagitscheva, "Microbiological Research in the Sulphurous and Salty Waters of Apsheron," *Azerbajdzanskoe Neftjanoe Khozjajstvo*, Nos. 6–7 (Baku, 1926).

6. ——— ———, "The Formation of Hydrosulphide and Mercaptans by the Microflora of Oil and Sulphurous Waters of Apsheron," *ibid.*, No. 3 (Baku, 1927).

7. ——— ———, "Microbiological Oil Research of the Oil and Sub-Soil Waters of Apsheron," *Izvestija Azerb. Politechniceskogo Inst.*, Vols. 4–5 (Baku, 1928).

8. B. L. Issacenko, *Examination of the Bacteria of the Arctic Ocean* (Leningrad, 1914).

9. ——— ———, *Microbiological Examination of Mudlakes.*

10. V. Omeliansky, "The Hydrogen Fermentation of Cellulose," *Archiv Biologiceskich nauk*, Vol. 7 (1899).

11. ——— ———, "The Methane Fermentation of Cellulose," *ibid.*, Vol. 9 (1902).

12. ——— ———, "The Natural Formation of Methane During Biological Processes," *ibid.*

13. ——— ———, *Handbook for Practical Microbiology* (Leningrad, 1922).

14. E. McKenzie Taylor, *Jour. Inst. Petrol. Tech.* (December, 1928).

15. Lewis A. Thayer, "Bacterial Genesis of Hydrocarbons from Fatty Acids," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 15, No. 4 (April, 1931), pp. 441–53.

16. N. G. Ushinsky, "The Problem of the Origin of Sulphurated Hydrogen on the Coast of the Caspian Sea," *Azerb. Oil Business*, Nos. 8–9 (1926).

17. V. E. Vernadsky, The Biosphere (Moscow-Leningrad, 1926).

18. ——— ———, *The Outlines of Geochemistry* (Gosizdat, Moscow-Leningrad, 1927).

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BASE-REPLACEMENT STUDIES OF OKLAHOMA SHALES— CRITIQUE OF TAYLOR HYPOTHESIS[1]

L. C. CASE[2]
Tulsa, Oklahoma

ABSTRACT

Clays of an alkaline nature which contain a predominence of replaceable sodium are stated by Taylor to overlie all petroleum deposits. These shales are said to have undergone base replacement in sea water and subsequent leaching in fresh water. An examination of several Oklahoma shales indicates that the base replacement did not take place in ordinary sea water, that the shales were not leached, and that all shales encountered in drilling in Oklahoma are of the one type and such determinations therefore have no application.

INTRODUCTION

Considerable work has recently been done on the replaceable bases and hydrogen ion values of shales[3] by E. McKenzie Taylor of Cambridge, England. Taylor began this investigation prior to 1928 and is continuing the studies at present.

This article covers some work done on shales in the laboratory of the Gypsy Oil Company during the year 1931. This work was begun for the purpose of investigating some statements made by Taylor concerning the characteristics of shales occurring above oil horizons. Although the results of the work do not cover so wide a scope as might be desired, considerable time was spent on the interpretation of these results and it is believed that the investigation was made as exhaus-

[1] Read before the Association at the Oklahoma City meeting, March 24, 1932. Manuscript received, May 18, 1932.

[2] Gypsy Oil Company.

[3] E. McK. Taylor, "The Bearing of Base Exchange on the Genesis of Petroleum," *Jour. Inst. Petrol. Tech.* (London), Vol. 14, No. 71 (1928), pp. 825–40.
———"The Replaceable Bases in the Shales and Clays Overlying Petroliferous Strata," *Jour. Inst. Petrol. Tech.*, Vol. 15, No. 73 (1929), pp. 207–10.
———"A Comparison of the Conditions of Occurrence of Bituminous Coal and Petroleum," *Jour. Inst. Petrol. Tech.*, Vol. 15, No. 74 (1929), pp. 372–84.
———"Base Exchange Between Clay and Solutions of Sodium Salts and Its Relation to the Formation of Coal and Petroleum," *South African Jour. Sci.*, Vol. 26 (1929), pp. 57–69.
———"An Examination of Clays Associated With Oil Bearing Strata in the United States," *Jour. Inst. Petrol. Tech.*, Vol. 16, No. 84 (1930), pp. 681–83.

tive as possible with the available literature and data and that the most important question of interest to oil geologists is fully answered.

ACKNOWLEDGMENTS

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OUTLINE OF THEORY

At the outset, Taylor stated that the phenomenon of base exchange in soils is well known. He assumed that this process took place also in past geologic periods and that the process may have had a bearing on the origin of coal and petroleum. In summary of his results he states[1]:

> Petroleum deposits are usually overlain by impervious shales. . . . An examination of these shales has shown that the characteristic constituent is sodium clay, and that this sodium clay has hydrolised in fresh water. This hydrolysis had two main results, (a) the production of impermeability in the shale and (b) the production of an alkaline medium containing sodium hydroxide.

The reaction in this process is said to be essentially: Na-clay plus water gives $NaOH$ and H-clay. Sodium clay is stable and permeable in the presence of salt water, but when it is subjected to the leaching action of fresh water it becomes impermeable. Taylor concludes that the alkaline solution produced by hydrolysis of the sodium clay is conducive to the life of anaërobic bacteria which produce oil; also that the impermeable shale serves to entrap the petroleum products thus formed. Taylor made determinations of several samples of shales from the United States, which are stated in the last reference given. In this, his latest article dealing with base replacement investigations, he further concludes that shales containing a predominance of sodium clay and having hydrogen ion values well above 7, which he says is proof of their having been leached, will be found above or associated with the oil in any oil fields of any country. He does not state, however, that such shales are invariably underlain by petroleum, as his work also showed that shales of the same type were found to overlie bituminous coal deposits. Taylor made several experiments in sub-

[1] E. McK. Taylor, *Jour. Inst. Petrol. Tech.*, Vol. 14, No. 71 (1928), p. 839.

jecting various types of organic matter to bacterial action under a sodium-clay roof. The results showed that, after leaching, the roof became impermeable to both water and gases and that the anaërobes caused the production of gas from some compounds and a decided, but less understood, metamorphism of other compounds. Because of the similarity of their occurrence under sodium-clay roofs and probable similar origin, he concludes that bituminous coal and petroleum must have been formed from different kinds of organic matter in order to arrive at the different compounds.

Thus, beginning as an investigator of soil phenomena, Taylor has built up, from the application of these phenomena to indurated shales, a theory which is very far reaching in scope and perhaps revolutionary in thought. Because of the fact that the whole theory is based on two main premises, and that these premises have been expanded to such proportions, it may be well to restate them.

1. The shales have undergone base exchange. When a silt containing calcium clay is carried in suspension and deposited in water containing sodium chloride, the sediment will contain sodium clay as a characteristic constituent. Other methods of forming sodium clay are the submergence of strata in salt water and the capillary rise of salt water from a salt water table. If sodium clay predominates in a shale, base exchange is taken for granted.

2. The shales were later leached by fresh water and the sodium clay hydrolised. Thus, hydrogen clay and sodium hydroxide are said to have been formed. The shales may have maintained an alkaline medium over long periods in this manner. If the pH (hydrogen ion value) of the shales is found to be above 7, then it is taken for granted that the shales have been subjected to the leaching process.

Geologists have found no fault with the first episode stated in the history of a shale formation. In the second process, however, the theory is somewhat contradictory to geological evidence as it calls for at least a minor unconformity above all such shales of marine origin. Even though an unconformity may be present and yet unnoticeable by lithological or faunal break, it requires that the land was above sea at that time. Such evidence is merely conjectural and does no more than cause the leaching process to seem illogical. After further study the second stage of the process seems somewhat untenable from a chemical viewpoint. Therefore, because the theory must, in its entirety, either stand or fall, according to the validity of both of the premises, it seems that an examination of several shale samples and a searching study of some of the fundamentals of the second process would be worth while.

From a practical point of view, it seems that the applications of such shale examinations would be the possible indication of the presence of oil below shale formations before drilling through them and the possible correlative value of such determinations in the stratigraphy of non-fossiliferous shale zones. Indications of the presence of oil beneath thick shale bodies when penetrating only the top of such formations is almost too much to hope for. However, it seems only logical that if such leached zones do exist in the shales above oil strata, there should be some way of identifying them and that such zones should be of considerable lateral extent.

WORK UNDERTAKEN TO INVESTIGATE POSSIBLE APPLICATIONS OF BASE-REPLACEMENT STUDIES

An attempt was made to secure a good spread of core samples for testing in order to determine if shales possessed certain characteristics depending on their position relative to oil strata. A correlation of these results should then show the application of such determinations.

The samples taken for study included shales in contact with oil and not in contact with oil, samples from the top and bottom of a shale bed, and outcrop samples for the purpose of testing the degree of leaching and presence of hydrogen clay.

STATEMENT OF RESULTS

Any statements regarding the possibilities previously stated should be made only after a consideration of as many of the facts as possible. Therefore it is necessary to state in detail the results obtained by Taylor on nineteen samples of shales from various parts of the United States, together with sixteen determinations of Oklahoma shales made in the laboratory of the Gypsy Oil Company. The calcium and sodium are stated in milligram equivalents per 100 grams of shale. This type of statement gives a true picture of the chemical values.

Check samples were run on all of the determinations. To test further the accuracy of the work, a composite sample, composed of 10 grams each of samples 3 to 9 inclusive, was determined and compared with the calculated average of these samples.

	Replaceable Na	*Ca*
Calculated average	12.1	3.7
Composite sample	12.3	3.8

TABLE I

REPLACEABLE BASES AND *pH* VALUES OF SHALES IN THE UNITED STATES*

Company	*Location (County)*	*Depth in Feet*	*Horizon*	*Remarks*	*pH*	*Na*	*Ca*
Gypsy	Hughes, Okla.	3,300	Top Cromwell	Gas	9.4	12.4	5.6
Gypsy	Lincoln, Okla.	3,303	Top Prue	Oil	9.2	7.2	.8
Gypsy	Tulsa, Okla.	1,565	Top Dutcher	Gas	8.6	Insufficient sample	
Gypsy	Tulsa, Okla.	2,048	Chattanooga	Oil	8.6	5.7	4.0
Gypsy-Marland	Osage, Okla.	2,584	Simpson	Oil	9.0	7.7	4.2
Marland	Grant, Okla.	?	Chattanooga	Oil	8.4	Insufficient sample	
Amerada	Smith, Tex.	5,317	Over Woodbine	?	10.4	21.0	5.0
Amerada	Smith, Tex.	5,112	Over Woodbine	?	8.6	16.8	2.3
Atlantic	Navarro, Tex.	2,857	Eagle Ford	?	9.0	19.0	6.6
Atlantic	Navarro, Tex.	2,985	Dakota	?	9.0	13.8	6.5
Western Gulf	Kern, Calif.	2,590	Miocene	Barren	9.6	11.2	4.1
Western Gulf	Kern, Calif.	3,612	Miocene	Barren	8.6	6.3	4.2
Western Gulf	Kern, Calif.	3,613	Miocene	Barren	8.4	6.3	4.4
Western Gulf	Kern, Calif.	3,595	Miocene	Oil at 3,600	8.8	8.7	1.8
Western Gulf	Kern, Calif.	3,597	Miocene	Oil at 3,600	8.8	7.3	3.4
Western Gulf	Kern, Calif.	3,598	Miocene	Oil at 3,600	9.0	5.8	2.2
Gulf	Caddo, La.	2,393	Tokio	Oil	9.2	17.6	6.6
Stand. of Calif.	Kettleman	6,386	?	Oil	9.6	27.7	9.9
Stand. of Calif. well?		6,080	?	Oil	9.8	29.6	7.1

* E. McK. Taylor, *Jour. Inst. Petrol. Tech.*, Vol. 16, No. 84 (1930).

TABLE II

SAMPLES FROM OKLAHOMA, DETERMINATIONS MADE IN GYPSY LABORATORY

	Company	*Location Section, Township, Range*	*Depth in feet*	*Horizon-Remarks*	*pH*	*Na*	*Ca*
1.	Roxana No. 1	30–19–4	3,635	Tonkawa series	7.1	4.3	3.7
2.	Gypsy core drill	5–19–1	646	Lower Permian red shale	8.0	11.5	4.5
3.	Blackwell No. 1	9–7–8	2,923	Lower part of shale	7.9	8.2	3.1
4.	Gypsy Peters No. 4	23–5–7	2,510	20 ft. above oil-saturated Gilcrease sand	7.9	11.8	3.8
5.	Gypsy Toge No. 4	20–6–6	2,810	Above shaly sand	8.7	15.5	4.0
6.	Gypsy Toge No. 4	20–6–6	2,817	Just above oil-saturated sand	7.3	9.9	2.7
7.	Pine Tiger No. 1	3–8–5	3,890	Woodford, just above oil-saturated Hunton limestone	7.3	4.2	1.6
8.	Gypsy Toge No. 3	20–6–6	2,837	In contact with oil sand	7.9	19.5	6.7
9.	Sinclair No. 2	29–6–6	2,677	Between two streaks of oil-saturated Cromwell sand	8.5	15.6	3.7
10.	Sample from outcrop near Tulsa, 6 ft. below base of Checkerboard				7.0	.0005	5.6
11.	Sample from outcrop near Tulsa, 25 ft. below Checkerboard limestone				6.9	.0013	8.1
12.	Sample from outcrop near Tulsa, from underclay of coal 12 ft. below Checkerboard. 2–6 in. below coal				6.9	.0064	12.3
13.	Sample from outcrop near Tulsa, as above but 0–2 in. below coal				6.9	.0071	12.8
14.	Sample from outcrop near Tulsa, basal 4 in. of underclay, taken at another point				7.1	.0059	10.8
15.	Sample from outcrop near Tulsa, from sandy shale 15 ft. below Checkerboard				7.1	.0045	6.8
16.	From tank pit of Marathon filling station, corner of Boston Avenue and Brady Street, Tulsa. Taken 10 ft. below surface. This shale lies between Checkerboard and Hogshooter limestones				7.4	.0079	5.12

Tests for replaceable magnesium were made on the composite sample and on several of the outcrop samples. It was found that this element was very low, traces being somewhat larger in the outcrop samples. Replaceable magnesium is a very important constituent of certain soils and important facts may be shown by the ratio of replaceable calcium to replaceable magnesium in soils. However, because magnesium is so low as to cause the methods of micro-chemistry to be used in its determination in shales, the applications of magnesium determinations in shale studies are doubted.

DISCUSSION AND INTERPRETATION OF RESULTS

A comparison of the two tables of determinations shows several general relationships and some noteworthy differences.

1. The *pH* values stated by Taylor are consistently higher than those of the deep samples determined in the Gypsy laboratory. His figures for sodium are also somewhat higher on the average. However, the relationships of predominating sodium and alkaline *pH* values are present in all the deep samples.

2. The outcrop samples are characteristically low in *pH* and sodium values, the predominating type of clay therefore being calcium clay. In these shales the leaching process has evidently passed the stage where alkalinity may be developed by the alteration of sodium clay. Such samples merely indicate how shales now deeply buried could have been leached under sub-aerial conditions.

3. The *pH* values given are obviously not in proportion to the amounts of replaceable sodium found. Because the *pH* is a measure of the amount of hydrolysis of sodium clay present, the fact that these figures are not in direct ratio proves the systems to be "buffered." The *pH* can not, therefore, have much significance.

4. From the amount of variation in the samples from approximately the same horizon in the Seminole area, it is shown that these determinations will have no correlative value in the stratigraphy of shales.

5. From a consideration of all the samples as shown in the tables, no well defined relationships can be seen between the nearness of oil and the magnitude of the *pH* or sodium values. A shale from the barren Red-beds is shown to be higher in *pH* value than several others which overlie oil.

The foregoing discussion should answer the questions of most interest to the oil geologists who are no doubt more interested in the

applications of such shale studies. Although the results of this study seem to be negative so far as oil prospecting is concerned, a further interpretation of these results should be of interest to the geologist who would come to a better understanding of some of the events in the history of shale formations. A discussion of some of the chemical fundamentals of the two phases, base replacement and later leaching, leads to some very interesting probabilities concerning the history of shales and subsurface waters.

BASE REPLACEMENT IN SHALES

In general it can be safely said that sodium clays are derived products rather than direct formations. That is, in the weathering process the clay which is first formed is probably never the sodium compound, at least rarely so. Rather, it seems much more probable that the sodium compound results subsequent to the formation of the clay through base exchange. If this general view is sound it follows that the clay materials in these shales have come in contact with a relatively high concentration of sodium salts. However, no experimental evidence is known in support of the proposition that a clay whose replaceable sodium content is as high as that of the samples stated could be formed as a result of the interaction of ordinary sea water with normal clay. The sodium content of ordinary sea water is not high enough to produce such results. Moreover, sea water contains about one equivalent of magnesium to 4.3 equivalents of sodium. As the so-called replacing energy of magnesium is greater than that of sodium, a clay in equilibrium with sea water would always contain more or less replaceable magnesium. In other words, the existing evidence strongly indicates that the clays such as those reported could not be formed by the direct action of ordinary sea water. Rather, we believe, that the salt solutions which have acted on these materials were of a much greater concentration than sea water and composed more predominantly of sodium salts.[1]

A study and analysis of many subsurface waters in the Mid-Continent field has shown that the average ratio of calcium equivalents to magnesium equivalents is near 3 to 1. In sea water this ratio is practically reversed, being 5 magnesium equivalents to 1 of calcium. This shows that the process which concentrated these subsurface waters to 5 or 6 times the salinity of sea water did so with the attendant loss of much of the magnesium. This relationship has long

[1] W. P. Kelley, personal communication.

been known to geochemists and several theories have been advanced to account for this reversed calcium/magnesium ratio. Although explanations of the process, however vague, are of interest to all geologists, space does not permit their discussion here. It may be stated that the processes are not well understood. The status of the problem is much like that of the origin of petroleum. Certain facts as to occurrence are known which are used to advantage. Detailed explanations of these facts will no doubt result from continued research. It is gratifying to one who has spent some years in the study of subsurface waters to find that the results of shale studies in a manner check those of the water studies.

As stated before, the shales examined did not contain appreciable replaceable magnesium, as they should have if their base replacement was effected in normal sea water. Experimental evidence shows that base replacement, as noted in these shales, took place, not in ordinary sea water, but in water of higher salinity and a lower percentage of magnesium. Most of the subsurface waters of the Mid-Continent fulfill these requirements. Results of the shale studies show that the concentration of the water in these sediments occurred, to some extent at least, immediately preceding the compaction of the shales, at which time they were rendered impervious to the passage of water.

LEACHING OF SHALES

Concerning the leaching of a sodium clay, Taylor says that sodium hydroxide and hydrogen clay are formed. Then

> if a reduction in the number of hydroxyl ions occurs, further hydrolysis will take place until equilibrium is again established. The hydrolysis of a sodium clay therefore affords a method by which the alkalinity of a solution may be maintained for a considerable period.[1]

Laboratory tests show this to be a fact, but to account for the process in nature requires some special conditions. The presence of very thin streaks or leached zones in a shale would no doubt account for the impermeability of a whole shale formation, provided that the shale was not already impervious due to compaction. However, the explanation of residual alkalinity in these shales is somewhat vague. Taylor accepts the presence of an alkaline *pH* as proof of leaching and formation of sodium hydroxide. He says, however, that the residue is hydrogen clay. It seems that the residue should be all that is left to

[1] E. McK. Taylor, *Jour. Inst. Petrol. Tech.*, Vol. 14, No. 71, p. 829.

test in a sample of leached clay. No solution is present; if it were present, the sodium hydroxide would not be left as such. Supposing that the shale consists mainly of sodium clay, when the ground and dried sample is placed in water the sodium clay must be hydrolised to produce the alkaline *pH*. Therefore, the alkalinity of a shale is no proof of the former leaching of that shale. Such an occurrence would have to be shown by a determination of the hydrogen clay present. Furthermore, a sodium clay which has never been leached should give correspondingly high results for *pH* values when tested in the manner previously mentioned.

The *pH* values are clearly not in proportion to the amount of replaceable sodium; therefore, there can be no doubt that the carbonates and silicates present act as buffer salts which vary the *pH* determinations in different degrees, according to the amount of soluble buffer salts present. In other words, the dissociation of sodium clay, in the presence of water, to hydrogen clay and sodium hydroxide is masked to some extent by the presence of the salts of the weak acids. Taylor states that hydrogen clays are acid, therefore there must be some dissociation of the H ions in a suspension of hydrogen clay. In hydrolysis, the $NaOH$ would doubtless be more highly dissociated than the hydrogen clays and all the H ions would combine with the OH ions in the solution to form water, leaving an excess of OH ions. Leaching, however, connotes a carrying away of the solution, leaving the residue behind. As hydrogen clays are found to be acid, this is actually what happens. Thus, by reasoning from the fundamentals of the process, a leached clay should rarely be expected to be alkaline, but more commonly neutral or acid. Furthermore, the alkaline *pH* values found by Taylor are an indication that the shales were either not leached, or if they were, that they came into contact with salt water at some later time in their history. The clays of present tidal flats, which are subject to the alternate action of salt and fresh water, should be examined to determine if their characteristics approximate those of the deep shales already examined.

It is hoped that, at some time in the near future, some samples from delta deposits and from tidal flats will be available for study in regard to this discussion. For the present, some simple experiments in physical chemistry will serve to illustrate the discussion.

Replaceable H ions in soils are usually tested by replacement with some neutral acetate. Due to the lack of this salt in the laboratory, some tests were made using sodium chloride, which should illustrate the principle.

Sample	pH in Neutral Distilled Water for 30 Minutes	pH in Neutral Normal NaCl for 30 Minutes	Loss	Qualitative Test for Impurities Possibly Affecting Accuracy of Foregoing Tests: $CaCO_3$	SO_4	Cl
3	7.9	7.9	0.0	Present	Nil	Appreciable trace
7	7.3	6.9	0.4	Nil	Trace	Appreciable trace
8	7.9	7.3	0.6	Nil	Trace	Appreciable trace
10	7.0	6.5	0.5	Nil	Very faint trace	Very faint trace

At the beginning of these tests, it was reasoned that the presence of replaceable *H* ions in the shale would cause a depression of the *pH* value when this was determined in *NaCl* solution, by the reaction: *H*-clay plus *NaCl* gives *Na*-clay plus *HCl*, which is the chemical opposite of the process as outlined by Taylor. It was also reasoned that the amount of the depression of the *pH* value, when tested in a standard salt solution, should be a better index to the individual characteristics of a shale than some of the other figures, provided that the presence of small amounts of other salts did not cause too much variance of the test. The tests were not at all conclusive. It seems that the presence of $CaCO_3$ in sample 3 very probably prevented a depression of the *pH* value due to the increased solubility of $CaCO_3$ in the salt solution. It also seems possible that hydrolysis may have been prevented, by the presence of *NaCl*, in samples 7 and 8, and that replaceable *H* ions are proved only in the case of sample 10.

Concerning the interpretation of *pH* values, Kelley makes the following statement.[1]

With as complex a system as that with which we are working it is not possible to give a complete explanation of the *pH* values. The deep shale samples show almost three times as much replaceable sodium as calcium. With other such materials, it has been found that the *pH* in distilled water varies from about 7.5 to 8.0. We refer in this case to materials which do not contain calcium carbonate. The explanation of the alkaline *pH* in such materials must involve the hydrolysis which takes place with the sodium clay. If instead of suspending the material in distilled water, neutral *NaCl* is used, hydrolysis is forced back, with a consequent lowering of the *pH*. If the sample contains $CaCO_3$ in addition to the replaceable sodium a still further complication arises, namely the effect of the $CaCO_3$ itself. It is difficult to prophesy what the *pH* of a calcareous shale would be when suspended in *NaCl* solution, for in this case the *NaCl* would tend to repress the hydrolysis of the sodium clay but at the same time it would increase the solubility of the $CaCO_3$. The former would tend to lower the *pH* while the latter would tend to raise it. Just what the net result would be is difficult to say. In general it is believed that materials having cation exchange power are not likely to contain more than traces of re-

[1] Personal communication.

placeable hydrogen when in equilibrium with $CaCO_3$. This of course depends somewhat on one's viewpoint as to what is meant by ion exchange and the term "base saturation." Although we use the term to denote that degree of saturation with bases attainable by prolonged leaching with neutral acetates, a still greater degree of saturation with bases undoubtedly results upon raising the *pH* of the medium. Base saturation, therefore, must be defined in terms of *pH*.

In any case, the *pH* of the shales, as stated, does not necessarily indicate previous leaching. The low salt content of these shales seems to be more evidence of leaching than the alkaline *pH* values. However, this is only an indication which should be checked by determinations of amounts of salts in many samples. It may be that the state of compaction of these shales will give an explanation of the paucity of salts present. Cores have been noted in the field, at the time of taking from the core barrel, to be very dry. Such lack of moisture in these shales indicates that any salts present would be small in amount and widely disseminated. In this connection it seems timely to mention perhaps the greatest objection of geologists to the leaching theory. One determination showed that the bottom of a shale bed had all the characteristics of the so-called leached shales of Taylor. This would require that the whole formation was leached. Because of impermeability due to compaction and because of the impermeability induced by the leaching itself, the leaching of entire shale beds seems impossible.

IMPLIED EVENTS IN HISTORY OF SHALE FORMATION

Taylor assumes some special conditions attending the formation of all cap-rock shales. In description of these conditions he makes the following specific statement.[1]

> Results indicate that petroliferous strata must have been deposited under such conditions that they were subjected to the alternate action of salt and fresh water.

In this way he takes for granted tidal flat conditions prevailing at some time in the history of the formation of all such shales, but he does not go further with the process or the mechanics involved. If we interpret this history implied by Taylor as simply as possible, it would consist of at least four stages as follows.

1. A clay is deposited in saline water. It becomes predominantly sodium clay.

[1] *South African Jour. Sci.*, Vol. 26 (1929), p. 67.

2. The sea recedes slowly, leaving a tidal flat subjected to the prolonged leaching of rain water. The clay becomes impervious.

3. The land is again submerged and more clay is deposited in salt water, upon the first clay. Other formations of limestones and sandstones are laid down upon the second clay to aggregate a thickness of approximately 3,000 feet, during which time the clays are indurated to form hard shales.

4. The land mass is elevated above sea and so remains at present. The shales at the bottom of the series are now encountered by drilling approximately 3,000 feet in the search for oil.

The seemingly well established fact that these shales did undergo base replacement, and the concentration of the solutions required for such chemical reactions, seems to be the first direct evidence concerning the nature of the waters in the shales at the time of their formation. None of the statements which have been made concerning the concentration of these waters can be taken to mean that the old seas were either more or less concentrated than present sea water. However, from the data now at hand, the logical sequence of events in the history of the shales was as follows.

1. Muds laid down in sea water.

2. Deposition of other sediments and partial compaction of the muds. Concentration of the enclosed water and contemporaneous loss of much of the magnesium.

3. Base exchange in the clays.

4. Compaction of the clays to form shales.

From a survey of chemical and geological evidence, it is concluded that the shales have remained undisturbed since the fourth episode. The main points of this simple statement of shale history differ markedly from that as outlined by Taylor.

CONCLUSIONS

A consideration of available data regarding base replacement studies and possible applications thereof leads to the following conclusions.

1. Base replacement probably did take place in these shales, but not in ordinary sea water.

2. Alkaline *pH* values, found in these shales, are no proof of leaching and hydrolysis. Other evidence causes the leaching process to be strongly doubted.

3. It seems that, in the Mid-Continent field, shales of predominating replaceable sodium, having alkaline *pH* values, will probably be universally found from Ordovician to Permian. The characteristics of these shales vary from well to well within one formation; therefore, they have no correlative value.

4. The theory that such shales will invariably be found overlying bituminous coal and petroleum has not been disproved. Taylor has stated that these shales are necessary as a roof for the preservation of oil and bituminous coal. It does not follow, however, that these bituminous materials are invariably found underlying this type of shales, because the original organic materials may not have been deposited under the sodium clay roof.

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GEOLOGICAL NOTES

GRAPTOLITES IN KANSAS

Graptolites were found in some cores taken at a depth of approximately 3,335–3,340 feet in the Zerger well drilled by the Amerada Petroleum Corporation in Sec. 16, T. 21 S., R. 3 W. The best specimens were sent by the undersigned to Rudolf Ruedemann, state paleontologist of New York, for identification. He reported on them in the following words.

> The graptolites turned out to belong to the group of minute species of *Climacograptus* that range from the middle Ordovician to the lower Silurian. The specimens you sent are closest or practically identical with *Climacograptus putillus* (Hall). I found the same species in 1923 in the Sylvan shale on Cole Brook, Oklahoma. The species also occurs in the Maquoketa shale in the north. It seems, therefore, from this meager material, that this part of the drill core is from a formation of middle Ordovician to Richmond age, most probably the Richmond and more particularly from beds of the age of the Sylvan shale.

This determination indicates that the upper Ordovician shale of southern Oklahoma, the Sylvan, can be traced in well logs as far as north-central Kansas. It also indicates that the Sylvan is the probable correlative of the Maquoketa of Iowa and Minnesota.

The readers of this *Bulletin* will recall that Udden[1] reported the first paleontologic evidence of Ordovician rocks in western Kansas. The diagnostic fossils were *Bryozoa* of Decorah age. These and similar fossils were more fully described by Twenhofel[2] in 1927. Two years later Fanny Edson[3] described cuttings from wells in which such *Bryozoa* had been found. The limestone which appears in the Kansas section between the Decorah and the Maquoketa is usually called the Viola. Fossils from this limestone were found in a core and described by R. L. Kidd.[4] They also are of upper Ordovician (Richmond) age.

W. A. VER WIEBE

WICHITA, KANSAS
October, 1932

[1] Jon A. Udden, "Occurrence of Ordovician Sediments in Western Kansas," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 10, No. 6 (June, 1926), pp. 634–35.

[2] W. H. Twenhofel, "Ordovician Strata in Deep Wells of Western Central Kansas," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 11, No. 1 (January, 1927), pp. 49–53.

[3] Fanny Carter Edson, "Pre-Mississippian Sediments in Central Kansas," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 13, No. 5 (May, 1929), pp. 441–58.

[4] R. L. Kidd, "Richmond Fossils in Kansas Viola," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 14, No. 10 (October, 1930), pp. 1351–52.

SOME EOCENE LOCALITIES IN SALINAS VALLEY DISTRICT, CALIFORNIA

Certain occurrences of Martinez (Lower Eocene) rocks in the California coast ranges west of Salinas River may be of interest to paleogeographers and students of the Eocene. Martinez fossils were collected near the center of the NE. ¼ of Sec. 30, T. 25 S., R. 10 E. This locality is in northern San Luis Obispo County (Adelaida Quadrangle), approximately one mile south of Nacimiento River. A similar collection was obtained in the NW. ¼ of Sec. 24, T. 25 S., R. 9 E. (Adelaida Quadrangle) on the east bank of Las Tablas Creek within a few hundred feet of its junction with Nacimiento River.

Professor Bruce L. Clark determined the age as Martinez from collections sent to him by the writer in 1925. Alex Clark, who visited these localities later, reported that the most common diagnostic forms were *Turritella infragranulata* Gabb and *Turritella pachecoensis* Stanton. The fossils occur in a coarse conglomeratic sandstone carrying pebbles and boulders of both volcanic and granitic rocks. This lithologic facies extends for several miles southeastward as a thinning wedge between Cretaceous and Vaqueros sandstones.

The Martinez was found in one locality in the Bryson Quadrangle, southern Monterey County. A meager collection was obtained from a massive, coarse-grained, pebbly sandstone on the north side of Gulch House Creek, ½ mile southeast of Bryson.

M. G. Edwards

Los Angeles, California
December 1, 1932

THE NAME "LILLIS FORMATION" IN CALIFORNIA GEOLOGY

This name was first coined by J. H. Ruckman, a student member of a party of field geologists of the University of California who worked in the region north of Coalinga in December, 1913. Ruckman wrote a thesis on his work, but this, unfortunately, was not published. Various authors have used extracts from it, the first of whom was John C. Merriam[1] in 1915. He attributed the name "Lillis" to Ruckman, placed it in the Oligocene, and gave a cross section in which he showed the formation to be between the Tejon (Eocene) and Temblor (Miocene).

[1] J. C. Merriam, "Tertiary Vertebrate Faunas of the North Coalinga Region of California," *Trans. Amer. Phil. Soc.*, New Ser., Vol. 22, Pt. 3 (1915), pp. 191–234; 49 text figs. [See p. 194.]

The following year Roy E. Dickerson[1] reproduced the same cross section, but omitted the explanation of the symbols used and did not mention the name "Lillis." Bruce L. Clark,[2] in 1918, referred to Ruckman's work, but he did not use the name "Lillis." Instead, he called the formation "Kreyenhagen," following Anderson and Pack,[3] and applied a new name, "Markley" (pp. 84–86), to a northward extension of at least a part of it. Hoping to get a better understanding of what Ruckman actually said and did, Olaf P. Jenkins,[4] in 1931, consulted the original thesis in the library of the University of California and published (pp. 159–62) an excellent abstract of the part which pertains to the formation here being considered. He also gave a very nearly complete annotated bibliography of the formation in chronological order.

According to Jenkins, Ruckman used the name "Lillis" as a group, including therein the "Domengine sands" and the "Oil field shales." The latter is equivalent to Merriam's use of the name "Lillis."

F. M. Anderson, who originally named the Kreyenhagen shale, applied the term to a part of the section north of Coalinga which lies wholly below the organic siliceous shale to which Robert Anderson and R. W. Pack transferred the name in 1915. In fact, F. M. Anderson definitely included this same siliceous shale in the "Monterey," following the general custom in such cases at that time. In order to correct the error of Robert Anderson and R. W. Pack, and to supply a name for the siliceous shale for use in paleontological studies, F. M. Anderson first suggested that the formation be called "Phoenix shale." This name was derived from Phoenix Canyon, a small branch of Oil Canyon just south of the old camp, "Oil City," about 9 miles north of Coalinga. I do not know of the name having been published, but it was

[1] R. E. Dickerson, "Stratigraphy and Fauna of the Tejon Eocene of California," *Univ. California Publ. Bull. Dept. Geol.*, Vol. 9, No. 17 (May 21, 1916), pp. 363–524, Pls. 36–46; 14 text figs. [See pp. 425, 462, Fig. 9.]

[2] B. L. Clark, "The San Lorenzo Series of Middle California," *Univ. California Publ. Bull. Dept. Geol.*, Vol. 11, No. 2 (July 16, 1918), pp. 45–234, Pls. 3–24; 4 text figs. [See pp. 63–64.]

[3] Robert Anderson and R. W. Pack, "Geology and Oil Resources of the West Border of the San Joaquin Valley, North of Coalinga, California," *U. S. Geol. Survey Bull. 603* (1915), pp. 1–220, Pls. 1–14.

[4] O. P. Jenkins, "Stratigraphic Significance of the Kreyenhagen Shale of California," *Mining in California* (April [Sept. 15], 1931), Rept. 27, State Mineralogist, No. 2, pp. 141–86; 11 text figs.

in more or less general use in private reports for some time. Upon discovering that "Phoenix" had been otherwise used in North American geology, Anderson substituted "Cantua shale," deriving the name from Cantua Creek. This term was printed in the programs of the meeting of the Cordilleran Section of the Geological Society of America at Berkeley, California, and the Pacific Section of the Paleontological Society, February 20–22, 1930. Prior to the meeting, Anderson discovered that that name had likewise been otherwise used in the literature and another substitution had to be made. This time he chose "Lillis shale," unaware that Ruckman and Merriam had long before made exactly the same application of the same name. During the progress of the meeting the name "Lillis" was used, but through some inadvertence someone sent an uncorrected copy of the program to the Pan-American Geologist and it was duly printed. There[1] the name "Cantua shale" appeared in the abstracts of three papers. A corrected list of titles in the program was printed in *Mining in California*[2] and in the *Bulletin of The Geological Society of America*,[3] in both of which the name "Lillis Shale" appears in the same three abstracts.[4] From this it is apparent that F. M. Anderson's "Lillis" is exactly synonymous with the "Lillis" of Ruckman and Merriam.

An attempt has been made to determine the actual dates of publication of the papers by Merriam and Anderson and Pack.

C. F. Skinker, Assistant Secretary of the American Philosophical Society, stated on June 24, 1932, that the paper by Merriam was issued between September 29, 1915, and November 22, 1915. A copy was received at the Library of the California Academy of Sciences prior to November 24, 1915. The Superintendent of Documents stated on June 24, 1932, that the Bulletin by Anderson and Pack was placed on sale at Washington, D. C., on October 12, 1915. A copy was received at the Library of the California Academy of Sciences on October 28, 1915.

Evidently these two reports appeared almost simultaneously and may have actually been released on the same date. The subject is of considerable importance for several reasons.

[1] *Pan-American Geol.*, Vol. 54 (August, 1930), pp. 77, 79, 80.

[2] Vol. 26, No. 2 (April, 1930), pp. 143, 144.

[3] *Bull. Geol. Soc. America*, Vol. 42, No. 1 (March, 1931), pp. 302, 305–07.

[4] See also in this connection O. P. Jenkins' paper, footnote 5, pp. 178–80

1. Merriam's use of the name "Lillis" has been overlooked by the U. S. Geological Survey[1] and G. E. Bailey.[2]

2. There is considerable objection to the tacit understanding among California geologists whereby Anderson and Pack's error in the interpretation of F. M. Anderson's name "Kreyenhagen" is perpetuated.

3. Some well informed geologists believe that the name "Kreyenhagen" should be allowed to lapse because it was originally applied by F. M. Anderson to two distinctive units south of Coalinga (in Canoas Creek), and north of Coalinga he expressly excluded the portion of the section to which Anderson and Pack subsequently transferred the name.

4. The first available name which was actually assigned to the formation and about which there is no ambiguity is "Lillis formation, Ruckman," Merriam, 1915.

5. There seems to be general agreement that the formation is a distinctive and mappable unit and deserves a distinctive name.

An attempt to enforce rigid rules of priority in geological nomenclature would probably cause more confusion than stability, as it has in the biological sciences. Under ordinary circumstances it would seem that common usage should be the principal guide in the selection of formation names. In the present case there will probably be less confusion if we continue to use "Kreyenhagen" in its erroneous and restricted sense than if we attempt to establish the unfamiliar, but strictly applicable term "Lillis." Whatever is done, due consideration should be given to all of the known facts. This case emphasizes the need for a Geologic Board, legally empowered to act, arbitrarily if need be, finally on formation names. Such an executive body might well be modeled after the Geographic Board, whose duties are similar, but in another field.

G. DALLAS HANNA

SAN FRANCISCO, CALIFORNIA
October 28, 1932

[1] M. Grace Wilmarth, "Names and Definitions of the Geological Units of California," *U. S. Geol. Survey Bull. 826* (1931), pp. 1–97.

[2] G. E. Bailey, "Checklist of the Geologic Formation Names of California," *Univ. Southern California* (July, 1923), pp. 1–15.

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DISCUSSION

CORAL REEFS AND ATOLLS

To students of fossil organic reefs or bioherms, the study of the reefs now growing in tropical seas is of prime importance. Few petroleum geologists have had the opportunity of making such studies in person and we must rely on descriptions by those who have had such opportunities. Fortunately there are many of these. The little book by J. Stanley Gardiner (Macmillan and Company, 1931) is one of the most recent and for clearness and conciseness leaves little to be desired.

Gardiner is primarily a biologist and much of his book is concerned with a concise and very readable description of the various organisms which inhabit the coral reefs and lagoons of the Indian and Pacific oceans and their functions in building the calcareous framework, in filling up its interstices, or in its destruction.

One feature is outstanding in all discussions of present-day reefs and on this all the various writers are in agreement. That is, that given the proper environmental conditions, temperature, salinity, depth, clear water, et cetera, organic limestone reefs or bioherms will be built up whether the predominant builders of the calcareous framework are corals or some of the various types of algae.

Gardiner's word pictures and diagrams of growing reefs and their environments are particularly clear.

> Coral reefs are essentially a feature of tropical waters and their characteristic appearance is that of a shelf or flat at the surface of the sea at low tide level. . . . In contrast with the gradual slope of the land found in temperate zones, yard by yard of which is exposed as the tide falls, the whole surface of this bench becomes exposed almost simultaneously (p. 7). Beyond the outer edge to seaward is a slope on which corals may be seen growing down to 20 fathoms. . . . The edge is in fact a narrow belt, where is waged a perpetual struggle between the destructive force of the breakers and the constructive growth of organisms . . . but off this seaward edge there is the ever-flowing undertow, and most unattached material is caught by this and carried down the slope to be lost in the depths below (pp. 7, 8).
>
> The presence of this current is peculiarly important to the building organisms on the seaward slope of reefs, since it gives them the environment of active water movement most suitable to their existence (p. 127).
>
> The breadth of the first seaward slope varies greatly, although the conditions appear to be almost uniform off atolls. The slope here presents the tailing off of the bottom from the reef flat usually to some depth between 25 and 50 fathoms. Outside this, off isolated reefs and banks in coral seas, is always found the "steep" to 120–250 fathoms, . . . A steep at these depths is common to all organically covered or formed tropical banks, and represents the angle of accumulation of coarse material from its surface. . . . It is a talus or scree slope, which is gradually extending to seaward the foundations upon which reef corals can grow. Its surface is so rough and at so sharp an angle that dredging gives little information about it, but in elevated reefs this slope should be easy to recognize, for its constituents lie "higgledy-piggledy" whereas the attached coral and other builders of reefs are all growing towards the light in a manner analogous to the trees and shrubs of the land (p. 128).

This talus or scree slope may be the interpretation of much of the material exposed in the Capitan limestone, as suggested by Crandall. The Capitan should be studied further with this interpretation in mind.

Where he enters into a discussion of the controversial subject of the origin of coral reefs we could wish that Gardiner had presented his argument in more detail. He outlines the subsidence theory of Darwin and then dismisses it with one sentence.

> It is superfluous to detail all the arguments opposed to the original Darwin theory, beautiful and attractive as it is, since one fact kills it, viz., that there is no such general filling in of lagoons by coral growth and by sediment as suggested (p. 146).

All of Gardiner's observations on the lagoons of atolls indicate that these lagoons are being enlarged by solution and are not being filled in.

> The lagoon floors are remarkably level except that plateau-like shoals may rise abruptly almost or quite to the surface. Except for these, each lagoon basin has an unvarying depth of its own. This depth is attained in open positions within a short distance inside the encircling reef, and nearly all lagoon shoals are flat plateaus edged by low submarine cliffs with little or no scree areas around them (p. 130).
>
> The variation and distribution of deposits in atoll lagoons can only be explained on the idea of solution and of the removal of mud in suspension in their tidal waters (p. 135).
>
> The study of Indo-Pacific lagoons shows clearly that most are not areas of sedimentation, but are explicable only on the theory of enlargement of the lagoon by removal of limestone. In atoll after atoll it was clear to us that the lagoon edges of shoals and of the encircling reef are being cut back rather than growing out (p. 137).

The writer is not inclined to question these observations or the conclusions drawn therefrom. On the other hand, they apparently are not in agreement with the results of experiments and observations recently made in the West Indies, where Field and others have shown conclusively that the fine calcareous muds are relatively insoluble in normal sea water. Field[1] points out, however, that

> Microbiological investigations in the West Indies region to date indicate that when a calcareous reef, shelly beds, or calcareous sands are raised above sea level, the optimum physical, chemical and biochemical conditions obtain for the solution and redeposition of fine grained, relatively pure calcareous mud.

Gardiner himself furnishes convincing evidence that most of the atolls of the Indo-Pacific region have been subject to recent uplift. He says:

> Not allowing for weathering, the islands of the equatorial belt of the Indo-Pacific give evidence of a minimum average change of level of between eight and ten feet, . . . Except for a few islets formed by recent wave accumulation, this change of level is universally found, and it is the dominant cause of formation of the islets of atolls. These, as loss nearly always exceeds gain in their rock areas, can scarcely be conceived as having come into existence without such a relative movement of land and sea (p. 36).

Gardiner described two atolls as characteristically illustrative of the principle of lagoon enlargement by solution. In one of these he states that the limestone of the islets is elevated 30 feet above sea-level. In describing the other, he mentions cliffs 15 feet high being undercut by lagoonal waters. All told, he makes an excellent case for the enlargement by solution of the lagoons

[1] R. M. Field, "Microbiology and the Marine Limestones," *Bull. Geol. Soc. Amer.*, Vol. 43, No. 2 (June, 1932), p. 493.

of recently elevated atolls. This fits in perfectly with the conclusions reached by Field and previously quoted.

Since Field and others have shown us that the calcium carbonate muds and sands are only slightly soluble in normal sea water, we may postulate meteoric waters, falling on the islands of the atolls and circulating downward and outward through the porous reefs and coral sands, as the chief solvent. Such solvent action would be effective only near the land and only to a limited depth below sea-level, the depth being a function of the height of the islands. This may explain why the atoll lagoons have a uniform depth and why this depth is reached only a short distance from the land. Were the sea water dissolving the limestone in the lagoon and thus enlarging it, we should expect a gradual increase in the depth of the lagoon toward its center, where the solution would have been longest effective, but this, according to Gardiner's description, is not the case.

But what about the lagoons of atolls that have not been elevated or that are slowly sinking? Here we have no observations to guide us, since Gardiner has shown that in the Indo-Pacific region recent elevation has been very general. If it could be shown that the lagoons of such atolls were being enlarged by solution, Gardiner would have a good case against the subsidence theory, but his evidence derived from recently elevated atolls is not at all convincing.

It is surprising that some of the investigators of present-day coral reefs have not inquired into the evidence furnished by fossil reefs, particularly with respect to the subsidence theory and other theories of the origin and growth of the reefs.

The writer is familiar only with some of the fossil reefs or bioherms on the western side of the Permian basin of Texas and New Mexico, particularly with the Capitan bioherm of the Guadalupe Mountains. This bioherm itself, or rather the group of bioherms, might conceivably be interpreted as having grown laterally outward from an older land mass, the fore-reef scree or talus slope of the earlier stages furnishing the foundation for the later bioherm growth. There is, in fact, strong evidence that during certain stages such growth did take place. When, however, we take into consideration the thickness of the lagoonal limestones of the Capitan bioherm group and their relationship to the bioherms, the conclusion is inevitable that subsidence of many hundreds of feet took place during the growth of the bioherms.

E. Russell Lloyd

Midland, Texas
October 10, 1932

PAPERS ON APPLIED GEOPHYSICS

Books which are no books.—Charles Lamb

A small number of choice books is sufficient.—Voltaire

During the past ten years, especially since about 1926, the literature of applied geophysics has grown by leaps and bounds. This growth has been brought about mainly, of course, by the intensive application of geophysical methods in the search for ores and for structures favorable to the accumula-

tion of oil. Geological, mining, and physical journals publish an ever increasing number of articles on geophysical subjects. The literature has become so vast that any one geophysicist can no longer be expected to read all papers printed in English, German, French, and Italian periodicals; during recent years many excellent articles have appeared in the Russian language, thus adding new complications for those not familiar with Russian.

Observant readers have long noticed striking differences between the majority of geophysical papers and articles published in current physical or foreign geophysical publications. It is the purpose of this paper to draw attention to these fundamental differences.

First, the discussions in geophysical papers are limited almost without exception to the results obtained. The authors of articles dealing with topics in experimental physics generally state the object of the research, describe the experimental procedure, the difficulties encountered and how they were overcome, give the sources of error, and finally tabulate the results. Their aim is to give a concise account of what they did with sufficient detail so that their experiments may be repeated by those readers who are also interested in the subject discussed. Matters are different in geophysical literature, especially in papers dealing with applied seismology. Such details of experimental procedure as are given are so antiquated and have been discarded so long that they are of little historical, and no scientific value. The difficulties which had to be overcome are mentioned generously enough, but not a word is added to inform the reader how they were conquered. The results are discussed elaborately and minutely, but the reader profits little from the knowledge that a certain structure was located by geophysical methods, because he has probably known of it for years, that is, since the discovery, and it has long since been leased up. It is safe to say that any competent physicist, given the problem of designing and building a set of apparatus for refraction shooting, would waste his time if he searched through recent geophysical literature in an effort to learn how the thing had best be done. He would finally be compelled to engage some one who had done this kind of work or to embark upon a long and expensive program of research.

Secondly, there is a subdued, almost imperceptible, personal element; one has the feeling that the author has an axe to grind; that he is not entirely impartial.

Third, there is a deplorable lack of references to previous publications and, as a consequence much repetition of material which the reader, if sufficiently interested, could look up if he were given the pertinent citations. It may be that this condition has arisen from lack of reading of geophysical literature due to repeated disappointments; when one knows beforehand that he will learn about the results only, he will probably lay the article aside.

Lest the reader receive the impression that this paper is written in an effort to discourage publication of geophysical papers, let it be stated here that such a result is not desired. There are not too many papers; as a matter of fact, volumes of new material could, and ought to be, written. But there are too many papers which exhibit glaringly the defects mentioned, articles with the "meat" left out, seemingly written in an effort to force one's name onto the printed page, discussions which have advertising, but little scientific, value.

Due, probably, to the circumstance that the major oil companies bought their own magnetometers and torsion balances when they first became interested in geophysical methods and conducted their own magnetic and gravitational surveys, while they neglected to organize research departments for the development of seismic methods, which were, consequently, improved by private and individual enterprise, the criticism voiced above applies in a higher degree to papers dealing with the seismic methods than to the host of others. Competition has been, and still is, very keen, not only between the major oil corporations, but also between the consulting geophysical companies. It should be said, in fairness to the latter, that but for the articles published by members of their staffs, nothing at all would be known by outsiders about the successes of the seismic methods, for the larger companies have very successfully kept their knowledge to themselves.

For the sake of clarity, one might refer to the papers which have appeared since 1925 on the reflection method. It is a singular fact that the classical papers by Rayleigh, Wiechert, Zoeppritz, Galitzin, Love, and Knott are a better guide for one about to embark on a program of geophysical prospecting by the reflection method than recent articles. In the old articles the difficulties which are likely to be encountered are indicated; longitudinal, transverse, Rayleigh, and Love waves are discussed, and their displacements, velocities, and relative energies are tabulated in their dependence upon geological structure and stratification. The transverse wave is slower than the longitudinal; it carries more energy but the frequency is low; hence times of arrival might not be recorded sharply. Furthermore, every discontinuity in the wave path is responsible for a refracted longitudinal and refracted transverse, as well as for a reflected longitudinal and transverse wave if the angle of incidence is greater than zero and less than critical. It would be difficult to ascertain whether a certain transverse wave had traveled as a transverse wave all the way or was due to a reflected or refracted longitudinal wave. The first wave arriving at the seismograph, if due to a sufficiently large charge of explosives, is longitudinal and is the only one of which one can be sure that it has not changed type during transit. Only longitudinal waves are desired, therefore, but the transverse make their presence known; a longitudinal vibration which has been reflected from a discontinuity at some depth may arrive simultaneously with a transverse wave which has traveled over a shorter path.

Thus wrote the old authors. After reading to this point the novice in reflection shooting would probably decide that one of his problems would be the elimination of the transverse wave. On this subject the old writers would fail him, and he would likewise derive no solace or comfort from recent papers. Reflection shooting is a secret subject; the most interesting and fascinating geophysical method, its successes known to the multitude, its failures only to those who experience them, has had none of its technical details revealed to the scientific public; it is for those to enjoy who work with it and for them only.

It is well known, as has been stated, that the highly competitive character of applied geophysical work is responsible for this lamentable secrecy. It is readily conceded, too, that organizations ought to keep the information,

gained by their research departments at considerable expense, secret as long as there is reason to believe that publication would make available to the competition valuable details of a technical nature. However, refraction shooting has almost faded out of the geophysical picture, and we have, nevertheless, had no papers giving descriptions of the apparatus, used a few years ago, which different geophysicists found most successful in prospecting by the refraction method.

In this connection, attention should be drawn to the thousands of refraction seismograms now in the files of the different companies which could, without any resulting financial loss, be made available to pure geophysics. Many of the old seismograms, obtained when the sound of the explosion was used to guess at the distance, show longitudinal and transverse or, perhaps, Rayleigh, waves. The velocities of these waves could be used to calculate Poisson's ratio for the shallow layers. These old seismograph records could also be utilized in investigations of wave paths.

More has been published on electrical and radioactive methods, in proportion to their commercial application in prospecting for structure by oil companies, than on seismic or gravitational methods. This may be due to a feeling, on the part of those responsible for publication, that since the reader would necessarily derive less benefit from a study of the paper than the author obtained from the work discussed, there would be little chance of loss due to publication.

It seems, then, that geophysicists must look to the endowed research institutions for reliable physical data on apparatus to be used in geophysical prospecting. It is to be regretted that lack of funds prevents their engaging in research in applied geophysics on a larger scale. Under present conditions, no one knows much more than he has learned from his own investigations. Until such time, therefore, as the endowed institutions can carry on geophysical research on a large scale, the organization with the most efficient and, perhaps, largest research department, will amass the most reliable and, consequently, most valuable pertinent information.

Having finished the diagnosis, it may not be amiss to suggest a remedy. Unless the geophysical publications adopt higher standards for the articles accepted for publication they will be faced with a loss of members and, subsequently, with a shortage of funds which will necessitate drastic reductions of the number of papers printed. Authors should be required to publish full experimental details, with drawings or photographs, or both, of the apparatus, schematic drawings of all electrical circuits, and a full discussion of the experimental procedure. The sources of error should be mentioned. All important data should be given. The approximations used in the interpretation of the data ought to be discussed and reasons given to show why the geological picture derived from the data is reasonable, not only in the light of what may be known of the geology of the area, but also from the data themselves. Many geophysicists seem to have the notion that geophysical surveys must agree with the geology of the area as far as such may be available. It seems to the writer that in at least a few instances the geology may be deficient, and where the geology is known there is no reason for doing geophysical work. Let geophysical work stand on its own merits, base all interpretations of re-

sults on the data alone, and learn from the mistakes in the event that such are made.

The editors of geophysical publications might avail themselves of the services of referees, whose identities would be unknown to the authors of papers, to read and pass comment on articles to be published. They would be guided by such criteria, identical with, or similar to, those outlined above, as are used by referees of papers submitted for publication to journals in other branches of science. Papers inferior to the standard adopted would be rejected by the referee. There is no reason why such rejection should cause ill feeling; at any rate, the authors of papers in other branches of science submit willingly to an analogous procedure, and as far as the writer knows the only effect has been a decided improvement in the quality of papers published. Authors who, for reasons of their own, wish to publish results only would engage the services of commercial printers and defray the expenses themselves as is done with all advertising matter.

The foregoing remarks were prompted by a genuine desire to improve the quality of geophysical papers, to lighten the financial load imposed on the geophysical societies by indiscriminate publication of papers of doubtful value, and to assure the members of such societies desirable journals. It is believed that unless members receive publications of decided merit, the membership will fall off; at any rate, membership ought not to be maintained for altruistic reasons but because it is worth the fee.

The writer's connection with an oil company may to some readers seem to place him in a vulnerable position in the light of the statements made above. It is only fair to remark that, though in compliance with the policy of the company regarding publication of results of research he has not published any comprehensive and detailed accounts of geophysical technique and procedure, he has not written any papers whatever since severing his connection with a university. It is impossible, then, that he could have erred in the direction pointed out by writing of results only. Whether sins of omission are damnable to a higher degree than sins of commission is beyond the scope of this paper.

L. W. Blau

Houston, Texas
November 18, 1932

PERMO-CARBONIFEROUS OROGENY IN UNITED STATES

Maastricht, Holland
21 St. Hubertuslaan
November 15, 1932

To Professor Charles Schuchert
Yale Station
New Haven, Connecticut

My dear Professor Schuchert:

I have had no opportunity as yet to thank you for the review in the *American Journal of Science* of July, 1932 (Vol. 24, pp. 88–89), of my treatise "The Permo-Carboniferous Orogeny in the South-Central United States,"

as it appeared in the *Proceedings of the Royal Academy of Amsterdam* (Vol. 27, No. 3, 1931); this was a more extensive elaboration of a shorter account with the same title, found in the *Bulletin of The American Association of Petroleum Geologists* (Vol. 15, No. 9, September, 1931, pp. 991–1058).

You rightly ask: "*is this orogeny really so tremendous*" as I conceived it? This is, indeed, the great question; we may theorize about it, but, unhappily, we can scarcely expect a decisive answer, for a considerable time to come at least. I need not repeat here the several points of my argument, taken from features of the mountains as well as of the foreland, in constant comparison with what we know of the front of the great Permo-Carboniferous system of Europe. Here in Europe the heart of the mountains, happily, is fairly well exposed to investigation, with ever more remarkable results as to the truly tremendous dimensions of the orogeny on this side of the Atlantic. In the United States the interior chains and the hinterland are buried under the very thick blanket of the Gulf Coast Tertiary and Cretaceous, and I fear beyond hope of much further discovery in the Gulf Plain. The mother stratum of the salt domes in the Houston district, on the basis of geophysical data, must lie at a depth of at least 15,000 feet, and more probably 20,000 feet. The drill has only been able to tell us that at Sulphur, Louisiana, the basis of the salt dome is much deeper than 9,200 feet (Barton). Consequently our only hope of learning something about the Paleozoic basement of this area is geophysical speculation. D. C. Barton has recently communicated a synopsis of our data on this subject at the 13th Annual Meeting of The American Geophysical Union (*Report of General Assembly National Research Council*, Washington, April 29, 1932). It appears that the salt domes of the coastal group lie in a broad areal trough of gravity minima, which is especially sharp in Louisiana and the axis of which coincides with the southern Louisiana salt dome line between Lake Charles and Crowley and runs approximately across the Vinton-Lockport-Iowa-Welsh-Roanoke-Jennings salt domes. Unfortunately, it is by no means certain what this low-gravity zone really means. Following Barton, I may mention four alternatives: (1) it may be wholly the effect of a deposit of low-density rock salt, the mother stratum of the salt domes; (2) it may be the effect of a synclinal trough, in which a salt lens lies axially and is arched up convexly into a salt ridge, or merely the axial zone of a thick salt lens; (3) it may be the combination of (a) a seaward increase in thickness of the sediments and the dip of the basement on which they rest, and (b) the regional increase of gravity in the Gulf sea basin (of still obscure origin, but probably connected with a thinning of the lighter outer crust and relative shallow depth of dense subcrustal elements). The greatest thickness of sediments does not coincide with the axis of the gravity minimum; the former lies at or off the coast; (4) in the combination may enter a western prolongation of Bowie's area of negative isostatic anomaly, which more or less coincides with the Appalachian trough, involving a westward curvature of this trough, while south of the Louisiana-Texas negative zone would follow a prolongation of Bowie's area of positive anomaly, which more or less coincides with the Appalachian Piedmont belt.

If this last interpretation of part of the anomalous effect holds true, it might be an indication of the *general* west-southwest trend of the Permo-

Carboniferous mountains under the Gulf coastal sedimentary blanket, apart from northward lobes of the outer front of the orogeny, so particularly conspicuous in the Ouachita Mountains proper.

The only chance, and I believe a fairly good one, to find *outcrops* of the interior structure exists in Chihuahua and Sonora and in uplifts in the Sierras of Coahuila. We know of an outcrop of Paleozoics at Torreon, on the border of the State of Durango (Permian), and even as far southeast as near Victoria in Tamaulipas (Mississippian and Permo-Carboniferous). Unfortunately, outcrops will probably be confined to smaller uplifts in the Tertiary folds, but they may give valuable evidence if we hit upon as favorable a spot as at Marathon or Solitario.

For the present, therefore, our data as to the interior zones of the greater Ouachita complex are extremely meager. If, however, it is truly a major world-orogeny, and, as I conceive it, encircling the southern rim of the Paleozoic continental mass of North America, and not a more or less local matter, it should be possible to find some traces of the continuation of these chains farther west. Here, unfortunately, we again enter very little worked territory, particularly in northwestern Mexico, and, moreover, the Paleozoic picture becomes very much obscured by the great sequence of Mesozoic and Tertiary revolutions which affect the Pacific side of the continent, and are almost continuous from Jurassic time to the present period. The Andine (late Jurassic) orogeny, in particular, has profoundly changed the sediments by regional metamorphism, aggravated by tremendous intrusions of batholiths.

Last winter, when I had an opportunity to revisit the United States, I gave some attention to possible indications of the late Paleozoic orogeny west of the Cordilleran front and discussed the problem with N. H. Darton, D. F. Hewett, R. T. Hill, P. B. King, W. S. Burbank, and other geologists, who kindly gave me the benefit of their extensive knowledge of these but imperfectly known vast regions.

The foreland chain of the Wichita-Amarillo Mountains does not stop at the front of the Sangre de Cristo Range, but evidently the west-northwest trend continues farther northwest and is traceable as far as western Utah. Even as far northwest as the Columbia plateau of Oregon, east-west ridges of Paleozoics emerge, crossed by the north-south Tertiary trends (E. L. Packard, *Amer. Jour. Sci.*, Vol. 15, 1928, p. 221). All these, however, are remodelled by Tertiary orogeny.

The general region of Arizona, New Mexico, Colorado, and Utah is dominated by a great positive mass, active through all geologic history. This Colorado plateau is composed of two separate major elements; the Front Range block and the Uncompahgre massif. They are separated by a marked zone of weakness, into which the Tertiary folds of the Sangre de Cristo system swing conspicuously. These folds at first constitute the west front of the Colorado massif in northern New Mexico and southern Colorado, and then, just south of the Arkansas River canyon, swing northwest in between the two blocks. These folds, revived by Tertiary diastrophism, continue in the Uintah Mountains, are crossfolded by the north-south Wasatch Range, but reappear beyond the Salt Lake Valley of Utah and are traceable in the same east-west trend as far as the Nevada border. A system of minor warpings of west-

northwest trend traverses the entire region. It may be very difficult to work out the Paleozoic structure underlying the Laramide and the late Tertiary orogenies. The uplift has been so considerable that the Pennsylvanian and in many places the Permian directly rest on the pre-Cambrian; the later Tertiary uplifts have added large areas of exposed pre-Cambrian floor, having caused the erosion of the entire remaining blanket of Paleozoic sediments. The enormous conglomerates in the Pennsylvanian, however, are ample proof of the importance of late Paleozoic orogeny; the Permian rests unconformably on different Pennsylvanian horizons and becomes increasingly clastic toward the pre-Permian land masses. The Arbuckle phase of the latest Pennsylvanian is conspicuously indicated, notably for the Sangre de Cristo system, but other locations in the Colorado massif and the Front Range block give evidence of the earlier Pennsylvanian Wichita phase.

The Wasatch Range shows strong overthrusting toward the east in Tertiary time (but also Mesozoic diastrophism): it constitutes the eastern edge of the great Cordilleran Paleozoic geosyncline. Already in the Uintah Mountains the Paleozoics are largely in limestone facies. The swing of the folds seems to indicate a northeastward lateral displacement of the entire Colorado (Uncompahgre) massif, not participated in by the Front Range block, at least not much after the Wichita phase in the early Pennsylvanian.

All this orogeny, however, is movement of a foreland type, similar to the orogeny in the Wichita and the Amarillo mountains and very distinct from the Ouachita type of mountain structure.

Along the southern and southwestern side of the Colorado massif in Arizona and southern New Mexico another system of post-Laramide, *late* Tertiary folds, partly overthrust, of the Sierra Madre system (after R. T. Hill) indicate a renewed push from the southwest, which, this time, did not again displace the Colorado buttress. These folds continue from southern Nevada to Tamaulipas. This orogeny is of Pliocene age in its major phases.

Main (outer) Ouachita system.—Toward the southwest the Paleozoic chains of the Ouachita system of the Marathon Mountains are lost under the Sierra Madre folds of the Mount Ord and Santiago ranges; they once more crop out in the small isolated dome of the Solitario. In both these erosional windows they are most vigorous (nappe-overthrusts) and the facies of the older Paleozoics remains of the same geosynclinal type. *What becomes of the Paleozoic mountains farther west?*

At first they are lost under the practically unknown mountains of Chihuahua and Sonora, but here more erosional windows may be expected on the uplifts.

In the southwestern desert province of Arizona, the Altar district of northwestern Sonora, the Mohave desert, and the cross ranges of southern California, *we again find indications of a near-by Paleozoic geosyncline, at the south.* This syncline is not identical with the early Paleozoic Cordilleran geosyncline. In Nevada the Paleozoics do not belong to the Cordilleran geosynclinal province proper, but they here show a tendency to thicken rapidly toward the west, a process apparently accelerated by the great crustal shorteinng in this region; they thicken from 400 to 12,000 feet in this area, mostly in the Cambrian section. The sedimentation seems interrupted in the Silurian.

The highly metamorphosed sediments of southwestern Arizona, southwest of the northern mountain region of the state, are again more shaly than the limestone facies of the plateau. The rocks are now marbles, interstratified with schists, some quartzites, and pierced by monzonite-granite intrusives. Sparse fossils indicate Pennsylvanian and Permian (Kaibab fauna) in this sequence. Marine Trias is reported from the Altar district in Sonora. Thick Paleozoic sections have also been reported from Sonora, but no study has yet been made of the area. In the Mohave desert ranges of California we also find highly metamorphosed Paleozoics. J. B. Tenney believes the orogeny to be lower Triassic.

In Arizona the younger formations seem to overlap progressively on the southwestern pre-Cambrian edge of the Colorado Plateau. Strong plication is post-Kaibab. The conglomerates in the Triassic Shinarump and Chinle formations are derived from a southern source and indicate elevated (and wooded) highlands in that direction, subject to erosion in early Triassic time. The metamorphism and plication, however, must be accepted with caution, because the only visible outcrops are in island mountains piercing the recent desert filling. It is just possible that both are caused by and restricted to monzonite intrusions, and that now only these hardened areas stand out in relief.

In the mountain region of northern Arizona conditions are strikingly different: there is no pre-Tertiary folding and no evidence of geosynclinal conditions. We are well on the interior plateau. The widespread Paleozoic sediments are irregularly deposited, in plateau facies, and not metamorphosed. In the Catalina Mountains, at Roosevelt Lake, Globe, Ray, the pre-Cambrian is covered by upper Devonian, Mississippian, and Pennsylvanian. In the south-eastern corner of Arizona, at Bisbee, these aggregate 5,000 feet. In the Chiricahua Mountains on the border of New Mexico the section includes Permian. Unconformities are in evidence at the base of the Moenkopi (Trias) and at the base of the Pennsylvanian.

All this suggests that in southwestern Arizona we are again on the edge of the Paleozoic continent of North America against the marginal geosyncline, and on the front of an arcuate chain of folded and metamorphosed Paleozoics in geosynclinal facies. If this is true, this southern metamorphosed zone might well be a western prolongation of the Ouachita geosyncline of Marathon, now turning west and northwest along the southwestern rim of the continental mass, possibly forming another plateau-ward lobe, with its apex in southwestern Arizona and southern California. We may find evidence of an outer Pennsylvanian-Permian foredeep belt, affected by a very late Paleozoic, perhaps early Triassic diastrophism (*cf.* Bissett phase of the Glass Mountains at Marathon). The Paleozoic trends are of course cross-folded and reformed by the Tertiary Pacific trends. In southern California, however, the Ventura-Santa Barbara cross ranges (largely controlled by faults) are highly suggestive of the older east-west trend. A continuation of this feature is indicated in the regional relief of the bottom of the Pacific Ocean, far out from the coast and continuing beyond the inner shelf. This suggests that we witness a *major* accident in the earth's crust.

In Nevada and southeastern California there is vigorous later thrusting toward the east and northeast, in two cycles: Laramide (Paleocene) and post-

Miocene. Some of the Laramide thrusts represent real nappes with many outliers. They are arcuate toward the northeast, very complicated, and connected with normal faults of great throw and general north-south to northwest trend. The thrust zone extends all along the southeastern state line of California. The Paleozoics are thrust on Kaibab and Moenkopi; they are non-metamorphic and comprise Cambrian, Devonian, Mississippian, and Pennsylvanian; pre-Cambrian is also involved. In eastern San Bernardino County the thrusts become lost against the great intrusive batholith of early Tertiary monzonite. In the Providence Mountains the Paleozoics are still non-metamorphic: we must still be north of the metamorphosed zone. In the western portion of this area the Trias is non-red, in Pacific facies, very distinct from the red facies of the Moenkopi of Arizona and most of Nevada (D. F. Hewett). Very little is known of the Paleozoics in the transverse ranges of southern California. The very few known fossils are Carboniferous. The schists may be in part Paleozoic (Darton).

In the Sierra Nevada unit the highly metamorphic Paleozoic Calaveras formation is considered Carboniferous. From the very thick slates of the Blue Canyon formation Mississippian fossils are reported. Indications exist that the major Jurassic revolution is preceded by an earlier metamorphism and by two Paleozoic phases at the top, and again lower down in the Calaveras sequence (*cf.* Ferguson and Gannett, *U. S. Geol. Survey Prof. Paper 172*, 1932). They may represent the Arbuckle and Wichita phases.

This very brief analysis of conditions found in the extreme southwest does not *prove* anything so far, but it contains some suggestive elements: there are indications of late Paleozoic diastrophism, of east-west old trends, and of a metamorphosed zone of geosynclinal deposition south and southwest of plateau conditions in Arizona and Nevada. Everything is much obscured by the strong Jurassic, Paleocene, and Tertiary orogenies of the Pacific province and much further study, here and in Mexico, will be needed before any more definite conclusions may be drawn. Progress with similarly difficult work in the eastern Alps of Austria has proved that it is possible to unravel such older events, even in the midst of most intense later orogenies. If my guess is right, that we consider the area in the southwest as the westernmost prolongation of the Ouachita zone, this supports my conception that this orogeny is "tremendous" and may be considered on a par with the enormous bundles of late Paleozoic folds which, east of the Atlantic, are such an important element of the skeleton of the present continent of Eurasia, south of the older Paleozoic and Archaic-Proterozoic nuclei. As the Alpine orogeny is recognized to encircle the globe in both hemispheres, the Permo-Carboniferous orogeny would do the same. This is to be expected, since here in Europe there is much evidence that the late Paleozoic orogeny was certainly not less important than the Tertiary Alpine revolution, probably more so. Where these former enormously wide and complex chains are known to encompass half the world, it would be curious if in the western hemisphere they should be confined to a few smaller orogenies of only local significance.

W. A. J. M. van Waterschoot van der Gracht

BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
VOL. 17, NO. 1 (JANUARY, 1933), PP. 97-101

REVIEWS AND NEW PUBLICATIONS

A Chapter in Earth Science History. The Geological Society of America 1888–1930. By HERMAN LE ROY FAIRCHILD. Heavy, fine-quality paper, 232 pp., 18 pls., paper cover, 6½×10 inches. (Judd and Detweiler, Inc., Washington, D. C., 1932.) Price, $2.50.

Here is a volume that every geologist will appreciate if he is seriously interested in his chosen science. The book should be on the shelves of everyone who is accumulating any sort of geological library; in any event it should be read through carefully by all who love geology and the progress it has made since the Greeks first began to give serious observation and thought to natural phenomena. It is not merely an admirable story of the creation and career of The Geological Society of America; but as the title indicates, it is a chapter in the history of geology in which the author leads up to this period from the beginning of all science and then looks ahead to the future at its close. Chapter One is entitled "Birth of Earth Science"; Chapter Two, "Geology in Western Europe"; Chapter Three, "Geology in America Before 1848"; Chapter Four, "Geology in America, 1848–1888." The succeeding chapters to 18 inclusive are devoted to The Geological Society of America with its history and many records of events and circumstances that tie into the progress of geology in America. There are included sixteen excellent photographs of distinguished geologists including the late R. A. F. Penrose, Jr. Chapter 19 is entitled "Geology since 1888 and Present Status"; Chapter 20 is "The Look Ahead."

Professor Fairchild refers to the fact that the life of the G. S. A. at the time of his writing covers 43 years and that he himself is nearly twice that age and furthermore that "half a century to an American—the denizen of a country with such a brief civilization—may seem as long as half a millenium to an old-world inhabitant." The author was secretary of the Society from 1891 to 1906 and president in 1912.

Joseph Stanley-Brown states in the preface to this volume that it was no light task that was assigned to this author-historian but that it was accomplished with dispatch and judgment and that the Society was fortunate in being able to entrust the putting of its chronicles in imperishable form to one whose intimate knowledge reaches back to their very beginning.

Some slight errors have crept into the tabulation of other societies listed on page 188; the Southwestern Association of Petroleum Geologists is listed separately from The American Association of Petroleum Geologists, whereas the former was parent to the latter, and for some reason the San Antonio Geological Society has the honor of being listed without mention of its numerous brothers. Evidently Professor Fairchild has been too busy on his main theme to get acquainted with all the late children of geological organization in America. But we will not quarrel over that.

TULSA, OKLAHOMA
November 19, 1932

JAMES H. GARDNER

Treatise on Sedimentation. By WILLIAM H. TWENHOFEL and collaborators. The Williams and Wilkins Company (Baltimore, Maryland, 1932). 2nd ed., completely revised; new illus. xxvi+914 pp., 121 illus. 6×9 inches. Cloth. Index. Price, $8.00.

The value of the *Treatise on Sedimentation* has long been apparent to American geologists. However, the first edition of a volume on such a comprehensive subject naturally would contain certain features that could be improved in a later edition. The second edition contains 890 pages of text compared with 641 in the first. It has 121 figures, which is double the quantity in the previous edition. The number of topics in the index has been increased from 800 to 2,000, which makes the present volume average slightly more than two index topics per page of text.

The second edition contains about 2,250 citations, which is an increase of nearly 800 over the first edition. The increase in number of references to the literature represents not only material published between 1925 and 1931, but also many papers omitted from the first edition. Typographical errors in the citations have been reduced considerably from the quantity in the former edition. The second edition has more footnotes calling attention to key references containing good bibliographies than does the first edition. However, it does not list the important literature at the end of individual chapters or sections, as do many treatises. In the first one hundred pages of the new edition, approximately 60 per cent of the citations refer to American publications, 22 per cent to British, and 18 per cent to those of other nationalities. This is an improvement over the ratio of 70 per cent American to 30 per cent foreign references mentioned by Boswell[1] as being the average for the first edition.

In the previous edition acknowledgment to the contributing authors was made by footnotes at the beginning of particular sections. In the present volume some of the contributors are indicated in the table of contents and in the text, but others are acknowledged only in footnotes.

The text has been revised considerably, but the outline and subheadings of the volume remain essentially unaltered. Certain sections, however, have been enlarged. Much of the additional material represents work published since the appearance of the first edition, but a significant proportion of it represents new treatment of certain subjects. The greatest modification is in Chapters V, "Products of sedimentation," and VI, "Structures, textures, and colors of sediments," which have been increased 50 per cent in length. Chapters I, "Sources and production of sediments," II, "Transportation, deposition, diagenesis, and lithification of sediments," and VII, "Environments or realms of sedimentation," contain about 20 per cent more material; and Chapters III, "Important conditions modifying sedimentary processes," and IV, "Sediments and organisms," are of approximately the same length in the two editions. Chapter VIII, "Field and laboratory studies of sediments," is shorter and has been completely rewritten.

The reviewer has used the previous edition with profit and he believes that the new edition will be even more useful than the first.

PARKER D. TRASK

WASHINGTON, D. C.
November 25, 1932

[1] P. G. H. Boswell, Review of the first edition of the *Treatise on Sedimentation*, *Geological Magazine*, Vol. 64 (1927), p. 181.

"Zur Entstehungsgeschichte des Golfes von Mexico" (History of the Formation of the Gulf of Mexico). By WALTHER STAUB. *Eclogae geol. Helv.*, Vol. 24 (1931), pp. 61–81, 6 figs. 1 pl. (maps).

In this highly interesting paper the geologic history of the Gulf of Mexico is described by the use not only of local geological data, but also of more general information, such as faunal connections with the eastern hemisphere.

The first indications of uplift on the west side of the present Gulf of Mexico are found in late Jurassic time in the Sierra Madre Oriental. The last important movements in this mountain range and in the Sierra Tamaulipas occurred in Eocene time (Wilcox). At this time there were three basins in eastern Mexico separated by the Sierra Tamaulipas and the Sierra Madre Oriental. The north basin, which included the Mississippi Valley embayment, was in connection with the Atlantic through northern Florida, while southern Florida was connected with the Bahamas, Antilles, and Yucatan. The other basins were in the present Tampico oil district and the Isthmus of Tehuantepec. Sedimentation during the Tertiary in these three basins is described. After being folded in early Oligocene the mountain ranges of the Antilles and Central America emerged. In middle Oligocene they again were partly submerged and only in late Oligocene did they appear as large land masses, the latest folding in the Antilles being in late Miocene. Only after Miocene time were the Yucatan Channel and the Florida Strait formed, connecting the Gulf of Mexico with the Caribbean Sea and the Atlantic and creating the Gulf stream, with its important climatic influence in the north Atlantic.

Of great interest are the paleogeographic and geologic maps, in the compilation of which the author's personal observations were used.

EDWARD BLOESCH

TULSA, OKLAHOMA
November 26, 1932

Oil Economics. By CAMPBELL OSBORN. Cloth; 6×9; 402 pp., 32 figs., 49 tables. (McGraw-Hill Book Company, Inc., New York, 1932.) Price, $4.00.

Mr. Osborn has covered what is a tremendously big and very diversified subject in a most thorough and understandable manner. He has treated it in such a readable and non-technical way that, whereas one would begin the book with the feeling that he must learn what is in it, he soon finds himself absorbed in a very interesting treatise.

With exception of a very brief and non-segregated discussion of oil royalties, every phase of the industry is covered in detail, from the search for oil to its consumption in a myriad of ways.

A number of chapters merit special attention. Chapter II, on "Financial Structure of the Industry," points out that the oil business, while not yet mature, has lost much of the glamour of romance and the amassing of fabulous wealth, and has settled down to a status where fortunes are made by only a lucky few, where the great majority gain nominal profits only by dint of hard work and good management, and the speculative remainder lose more often than they win.

Chapter IV is a particularly interesting review of the progress of our country in the past 70 years as reflected in the growth and diversification of the use of petroleum products. For the future the author is of the opinion that "it seems questionable whether the past rate of growth can be maintained unless the refiner and marketer unite their efforts and by collective thinking, research, and action vigorously attack the problem of developing new channels of consumption."

The question of substitutes for petroleum is discussed in Chapter VI. Figures are presented to show that tremendous quantities of motor fuel substitutes for gasoline are available, but that these must await a more favorable (or unfavorable to gasoline) price condition. There appears to be no substitute for lubricating oil.

Chapter VII sets forth in an interesting manner the conflict for business between the major transporting units, pipeline, railroad, and tank steamer. Much valuable data on the cost of transportation and storage are presented in this chapter.

The introduction to Chapter X points out that the prime purpose of the book is to lay the necessary foundation for the estimation of future prices. This chapter and the one following contain an exhaustive analysis of the price situation in both crude and refined products.

The Chapter (XV) on Valuation is notable in that it covers the principles and methods in considerable detail. This chapter contains much that is learned only by long experience, and that rarely finds its way between the covers of a book.

The final chapter, "Conservation of Oil and Gas," is particularly worthy of mention because of its treatment of some relatively new questions. Physical Waste; Economic Losses; the Unit Plan, Proration, and Government Regulation; the Tariff; are treated in an able manner.

The book is indeed a worthy reference work for all within the industry, and a liberal education for those who may be interested, but not experienced in it.

HARRY F. WRIGHT

TULSA, OKLAHOMA
December 6, 1932

RECENT PUBLICATIONS

CALIFORNIA

"Geology of Santa Cruz Island, Santa Barbara County, California," by Carl St. J. Bremner. *Santa Barbara Mus. Nat. Hist. Occasional Paper 1* (Santa Barbara, 1932).

COLOMBIA

"Zusammenhang von Erdöl und Salz in Kolumbien (Südamerika)" (Association of Petroleum and Salt in Colombia, South America), by Ermisch. *Zeits. f. prak. Geol.*, Vol. 40, No. 10 (Halle, Saale, Germany, October, 1932).

FRANCE

La Géologie et les Mines de la France d'outre-mer (Geology and Mines of French Colonies). Collection of papers and lectures by 14 authors delivered at the Museum of Natural History, Paris, 1931–1932. Chapter 20 is "Le pétrole dans les possessions Françaises," by L. Bertrand (pp. 505–56). A publication of Bureau d'Études, Géologiques et Minères Coloniales. (Soc. d'Éditions géographiques, Paris, 1932). 604 pp., 38 figs., 2 pls. $6\frac{3}{8} \times 9\frac{5}{8}$ inches. Paper. Price, 60 francs.

GENERAL

Supplemental Geologic Index of the Publications of the United States Geological Survey, by George H. Albertson. Brings up to date (1932) the Index published in 1931, including topographic sheets for Alaska, none of which was listed in the 1931 Index. 15 pp. (Geological Publishing Company, Denver, Colorado.)

Origin and Environment of Source Sediments, by Parker D. Trask. Gulf Publishing Company (Houston, Texas, 1932). 323 pp., 6×9 inches. Fabrikoid binding. Price, $6.00.

GERMANY

"Die Erschliessung von Erdgas in Weiner Becken" (Natural Gas in the Vienna Basin). *Petrol. Zeits.*, Vol. 28, No. 40 (Vienna, October 5, 1932), pp. 1–4; 3 figs.

"Neuerbohrung von Erdöl in Österreich" (Recent Drilling for Oil in Austria). *Petrol Zeits.*, Vol. 28, No. 46 (Vienna, November 16, 1932), pp. 6–11; 4 figs.

TEXAS

"The Tertiary and Quaternary Geology of the Lower Rio Grande Region, Texas," by A. C. Trowbridge. *U. S. Geol. Survey Bull. 837* (1932). 256 pp., many illus., including 16 pls., geologic map on scale, 1:500,000. (Supt. Documents, Washington, D. C.) Price $0.75.

WEST VIRGINIA

Coal in Monongalia County, by Lee M. Morris. 122 pp., 33 illus. (West Virginia Geol. Survey, Box 879, Morgantown, 1932.) Price, $1.50.

Geological Map of West Virginia, in coöperation with U. S. Geol. Survey. Contains two cross sections by R. C. Tucker. Scale: 1 inch equals 8 miles. (West Virginia Geol. Survey, Morgantown, 1932.) Price, folded, $1.00; rolled in tube, $1.25.

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Memorial

GEORGE IRVING ADAMS

George Irving Adams died of a heart attack at the University of Alabama on September 8, 1932, following an illness of several weeks.

Dr. Adams was born in Lena, Illinois, August 17, 1870. Later his parents, Howard Brooks and Ruth Ann Adams, moved to Kansas, and he graduated from Kansas State Normal School in 1889. He received his A.B. degree from the University of Kansas in 1893 and his A.M. from the same institution in 1895. In 1896 he received his Sc.D. from Princeton University and the following year continued his graduate work at the University of Munich. After his return from the Philippines in 1910 he spent a year at Yale University in graduate study.

Dr. Adams began his teaching career as instructor in natural science at Kansas State Normal School in 1893. During the years he was at the University he worked on the Kansas Geological Survey and published articles on local problems of stratigraphy and paleontology. In 1898 he became field assistant on the United States Geological Survey and in 1900 assistant geologist. During the five years he was on the Geological Survey he published extensively, many of his writings being in conjunction with the foremost geologists of that time. In 1904 Dr. Adams left the United States and spent the next decade and a half of his life in distant parts of the globe. He became chief hydrologist for the Cuerpo de Ingenieros de Minas del Peru from 1904 to 1906 and spent the following year in making examinations of mines in Peru, Bolivia, and Chile. In 1908 he became geologist of the Division of Mines, Bureau of Science, Philippine Islands, where he remained two years, and then, after a sojourn at Yale University in 1911, he became professor of geology and mining at Pei Yang University, Tientsin, China, and in 1915 professor of geology at the Peking Government University. This position he held until he became professor of geology and mineralogy at the University of Alabama in 1920.

During the years Dr. Adams spent at the University of Alabama he was very active in University work and in the promotion of research, especially research carried on by faculty members. He assisted in the organization of the University Research Council and served as president. In his death the University lost a much beloved teacher and an indefatigable worker. With the help of only a few student assistants he carried on the work of the entire department of geology and systematized the lecture and laboratory work to enable the inadequately trained graduates of the smaller high schools to derive the maximum benefit from his courses.

Notwithstanding his heavy duties, Dr. Adams found time to continue his own research on the geology of Alabama. During the summers he acted as geologist on the Geological Survey of Alabama and later became assistant

state geologist. He continued to write on subjects of geological interest, his publications numbering more than fifteen during the time he spent in Alabama.

A short time before his death Dr. Adams compiled his bibliography and the complete list comprising seventy-two titles is on file at the library of the Geological Survey of Alabama. During his stay in China Dr. Adams was decorated by the Chinese Government. He was archivist of the local chapter of Phi Beta Kappa at the University of Alabama, he was a fellow of The Geological Society of America and a member of The American Association of Petroleum Geologists, the American Institute of Mining and Metallurgical Engineers, the Mineralogical Society of America, the Washington Geological Society, and the Cosmos Club of Washington.

In 1914 he married Miss Bertha Barin of Portland, Oregon, by whom he is survived. There are no children.

D. R. Semmes

San Antonio, Texas
November 19, 1932

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AT HOME AND ABROAD

CURRENT NEWS AND PERSONAL ITEMS OF THE PROFESSION

J. Versluys, professor of economic geology and mineralogy at the University of Amsterdam, Holland, is the author of a pamphlet, *De Ontwikkeling der Economische Geologie* (Development of Economic Geology).

William H. Spice, Jr., formerly with the Lago Petroleum Corporation at Maracaibo, Venezuela, is associated with F. B. Lefevre, dealing in oil properties, Room 2117, Alamo National Building, San Antonio, Texas.

Marvin Lee, of Wichita, Kansas, is executive vice-president of the Independent Petroleum Association of America.

J. A. Waters, secretary-treasurer of the Dallas Petroleum Geologists, now has available at $1.00 per copy, postpaid, a second edition of the report, *The East Texas Oil Field*. Orders may be sent to Box 2880, Dallas, Texas.

Erasmus Haworth, former state geologist of Kansas and professor of geology at the University of Kansas, died at the age of 77 years, at Wichita, Kansas.

C. A. Heiland, professor of geophysics at the Colorado School of Mines, Golden, Colorado, has written an 88-page publication of the American Askania Corporation entitled, *Directions for the Use of the Askania Torsion Balance*. He is also the author of "A Demonstration of the Geologic Possibilities of the Resistivity and Magnetic Prospecting Methods," in *Terrestrial Magnetism and Atmospheric Electricity* for September, 1932.

William Allen Thompson, who has been employed by the United States Engineers at Rock Island, Illinois, during the past three years, is on furlough at Des Moines, Route One, Iowa.

R. E. Collom, general manager of operations in California for the Continental Oil Company, has been transferred to Ponca City, Oklahoma, headquarters.

Mason L. Hill, University of Wisconsin, has a paper in the August-September, 1932, issue of *The Journal of Geology* entitled, "Mechanics of Faulting near Santa Barbara, California."

A. E. Fath, formerly of Room 100, 26 Broadway, New York City, is now in Germany and may be addressed at Semperhaus B/III, Hamburg 1.

Victor P. Grage, recently associated with the geological department of the Gulf Refining Company of Louisiana, Shreveport, has entered the University of Oklahoma to complete requirements for a Master's Degree.

Recent talks before the Tulsa Geological Society were the following: "A Trip to Nicaragua," by CARROLL H. WEGEMANN; and "The Reflection Seismograph," by EUGENE MCDERMOTT.

E. C. TEMPLETON, of Los Angeles, California, and W. G. GALLAGHER, of Beeville, Texas, were killed in an airplane accident at Wharton, Texas, November 21, 1932.

The ninth annual meeting of the Pacific Section of the Association was held at the Biltmore Hotel, Los Angeles, California, November 3 and 4, 1932. FRANK A. MORGAN is the new president of the Section, succeeding CARROLL M. WAGNER. The following papers were presented.

"The Rôle of the Petroleum Geologist in the Problems Confronting the Oil Industry Today," by FREDERIC H. LAHEE
"Analysis and Effects of Current Movements on an Active Thrust Fault in Buena Vista Oil Field, California," by T. W. KOCH
"The Speed of Migration of the Extremely Heavy Oils of the Casmalia Type," by WILLIAM W. PORTER, II
"Progress of Geologic Branch of the California State Division of Mines," by OLAF P. JENKINS
"Some Problems in the Correlation of Miocene Formations in California," by W. D. KLEINPELL, R. D. REED, M. G. EDWARDS
"Contribution to the Subsurface Stratigraphy of the Kettleman Hills Field," by PAUL P. GOUDKOFF
"Fauna of the Merychippus Zone, North Coalinga District and the Miocene Sequence of Mammalian Assemblages in California," by FRANCIS D. BODE
"The Knoxville-Shasta Succession in the Coast Ranges of California," by F. M. ANDERSON
"Tertiary Stratigraphy in the Tesla and Carbona Quadrangles, California," by R. G. GREENE
"The Problem of the 'San Diego' Formation," by A. J. TIEJE and GLENN FERGUSON
"Notes on the Geology of the Rincon-San Miguelito Area, Ventura County, California," by R. E. STEWART
"Correlation of Reflection Seismograph Records in California," by HENRY SALVATORI
"Pliocene Conglomerates of the Los Angeles Basin and their Paleogeographic Significance," by EVERETT C. EDWARDS

A. M. ALEXANDER may be addressed at 18 East 199th Street, New York, New York.

H. BRITTON THOMSON is division production engineer for the Texas Producing Division of the Pure Oil Company at Forth Worth.

MALVIN G. HOFFMAN, Washington State College, Pullman, Washington, has a paper entitled, "The Geology of Bald Butte Ridge, Washington," in the October-November issue of *The Journal of Geology*.

GEORGE M. BEVIER, geologist, announces the opening of an office at 609 Sterling Building, Houston, Texas.

JEAN O. NELSON, for the past year district superintendent of production in the East Texas field for the Lion Oil Refining Company, is now doing exploration work in the South Texas district for the same company. He may be addressed at 1919 West Magnolia Street, San Antonio, Texas.

VAUGHN W. RUSSOM, geologist for the Sinclair Prairie Oil Company, has been transferred from Tyler to Livingston, Texas.

T. S. LOVERING, associate geologist, U. S. Geological Survey, Golden, Colorado, is the author of a paper "Field Evidence to Distinguish Overthrusting from Underthrusting," in *The Journal of Geology* for October-November, 1932.

J. WHITNEY LEWIS has returned to Dallas after spending the summer in California, and may be addressed at 5645 Gaston Avenue, Dallas, Texas.

W. A. WILLIAMS has severed his connection with the Crown Central Petroleum Corporation, and may be addressed at 633 First National Bank Building, Houston, Texas.

The Dallas Petroleum Geologists elected the following officers at their regular annual meeting in December: chairman, Leonard W. Orynski, The California Company; vice-chairman, Joseph M. Wilson, Simms Oil Company; secretary-treasurer, J. A. Waters, Sun Oil Company.

O. C. CLIFFORD, formerly with the Indian Territory Illuminating Oil Company, at Bartlesville, Oklahoma, is now with the Seismograph Service Corporation, 906 Cosden Building, Tulsa.

DONALD C. BARTON, consulting geologist, of Houston, Texas, presented a paper, "The Plan of Alignment of Gulf Coastal Salt Domes and Gulf Coastal Geosynclines," before the Shreveport Geological Society, December 2.

GRAYDON H. LAUGHBAUM, of the production department of the Sinclair Prairie Oil Company, has been made geological engineer for the same company and is now located at Covington, Oklahoma.

J. DAVID HEDLEY, geologist for the Barnsdall Oil Company, has been transferred from San Antonio to Houston, Texas.

IRWIN ROMAN, assistant professor of mathematics and physics at the Michigan College of Mining and Technology, Houghton, Michigan, formerly employed by the Geophysical Research Corporation, has invented a device for surveying drill holes, consisting of the following parts: a tubular casing which can be lowered into the drill hole; two magnetic compasses, one near the bottom of the tube and one near the top; an incandescent lamp and a lens which cause parallel rays of light to pass up through the tube; a photographic or other recording device in the top of the tubular casing.

F. H. LAHEE, since his return from his presidential speaking tour of local geological societies on the Pacific Coast, in Canada, the Rocky Mountains, and the northern Mid-Continent, last November, has talked on the "Affairs of the Association" before the following societies: Dallas Petroleum Geologists, December 5; Shreveport Geological Society, December 9; East Texas Geological Society, December 10; and Oklahoma City Geological Society, and Shawnee Geological Society, December 19.

Structure of Typical American Oil Fields, Volume III, is being prepared for publication late in the spring of 1933 as a memorial to SIDNEY POWERS, who had nearly completed the editorial work before his death last November. The book will be composed of general papers on the origin, migration, and accumulation of petroleum. Advance subscriptions to this special memorial

volume are now being received at Association headquarters. The price is $5.00 per copy. The Association proposes to devote any profits from the sale of this volume to the establishment of the Sidney Powers Memorial Publication Fund. Additional amounts, as cash contributions to the Sidney Powers Memorial Publication Fund, may also be sent to Association headquarters. This fund, administered by the executive committee, will provide for publication of other books on subjects appropriate for such a fund.

The East Texas Geological Society, on November 10, at Tyler, Texas, elected officers as follows: president, J. S. HUDNALL, Hudnall and Pirtle; vice-president, G. L. BOLYARD, Barnsdall Oil Company; secretary-treasurer, F. H. SCHOUTEN, Stanolind Oil and Gas Company.

The Oklahoma City Geological Society has elected the following officers for the year 1933: president, Baxter Boyd, 1224 N. W. Thirty-First Street; vice-president, H. S. Thomas, Slick-Urschel Company; secretary-treasurer, G. C. Maddox, Carter Oil Company; recording secretary, E. I. Thompson, Phillips Petroleum Company.

DONALD B. WINES, formerly of 733 East Clinton Street, Howell, Michigan, is now in the geological department of the Phillips Petroleum Company, at Bartlesville, Oklahoma.

JOHN B. KERR, consulting geologist with headquarters at Foreman, Arkansas, has been in California during the past four months in connection with mining and oil and gas matters.

RALPH D. REED, chief geologist of The Texas Company (California) at Los Angeles, and editor of the Association, is the author of *Geology of California*, a new publication of the Association to be ready for distribution within a few weeks. The book is a special publication entirely outside the monthly *Bulletin* and contains approximately 350 pages, 29 halftones, and 35 line drawings. It is cloth bound, size 6×9 inches. The prepublication price is $4.00 per copy, postpaid, no discounts allowed. After publication the regular price will be $5.00. Order now from Association headquarters, Box 1852, Tulsa, Oklahoma.

SHEPARD W. LOWMAN presented a paper before the Tulsa Geological Society, Monday evening, December 19, entitled "Subsurface Stratigraphy of the Middle and Lower Pennsylvanian of Oklahoma North of the Arbuckle Mountains and East of the Meridian."

FRED W. BARTLETT, geologist for the Shell Petroleum Corporation, and formerly of Dallas, is now at Houston, Texas.